Estuarine Foraminiferal Communities in Lake Illawarra, N.S.W.

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Lake Illawarra is a shallow brackish coastal lagoon which formed behind a marine sand barrier following the last rise in ocean level. It is connected to the ocean by an active tidal channel. Tidal flushing of the lagoon is slow and it ranges in salinity from 16‰ to 40‰. The lagoon is rapidly filling with sand and silt, with the sand mainly confined to banks around the lagoon margins. The substrate and turbidity of the lagoon control the distribution of floral communities which, in turn, influence the benthic invertebrates.

The distribution and composition of estuarine foraminiferal communities in Lake Illawarra depend on salinity, substrate and the rate of tidal exchange. In semi-enclosed estuarine lagoons the diversity of foraminiferal assemblages shows a marked decrease from the open ocean to the body of the lagoon. The connecting channel between the lagoon and the ocean is subject to diurnal tidal flushing and it contains a mixed assemblage of reworked and living intertidal and subtidal species with minor contributions of lagoonal species. The assemblage in the mobile sands of the tidal channel is much lower than on the seagrass-covered banks of the channel. Within the main body of the lagoon, where salinity is slightly lower than in the open ocean and tidal exchange is minor, foraminiferal assemblages are controlled by the substrate and its associated floral constituents. The sandy sediments around the margin of the lagoon have a foraminiferal assemblage characterized by a range of textulariinid species whereas the deeper and silty portions of the lagoon are dominated by two species of rotaliinids. *Ammonia beccarii* is an environmentally-tolerant species occurring at almost all the lagoonal to intertidal marine sample sites. Foraminifer population densities in the lagoon range from high to very low or absent depending on the quantity of available oxygen at the sediment-water interface.

In New South Wales, lagoonal foraminiferal communities differ significantly from communities developed in more open estuaries where tidal exchange is rapid. In the latter foraminiferal communities are more diverse and depend largely on the substrate and water depth, with salinity variations only affecting populations in the upstream portions of the estuary.

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INTRODUCTION

The distribution of foraminifers in Lake Illawarra, a coastal lagoon located 80km south of Sydney in New South Wales, has been determined from 132 samples collected from the lagoon, its tidal entrance channel and the adjacent marine intertidal Windang Island. The purpose of this study is to describe the faunal composition and distribution patterns of the foraminifers in the lagoon and adjacent upper intertidal environments.

Foraminiferal assemblages have been described from a number of bays, estuaries and lagoons along the coast of New South Wales (e.g., Albani, 1968, 1978, 1979, 1981; Albani and Johnson, 1976; Cotter, 1980) and from other Australian coastal environments (e.g., Apthorpe, 1980; Cann and Gostin, 1985; Collins 1958, 1974; Parr, 1932, 1945; Quilty, 1976). In addition, a number of studies have provided information about the physical parameters and seagrass communities in N.S.W. estuarine environments (e.g., Anderson and Story, 1981; Anderson *et al.*, 1981; Eliot *et al.*, 1976; Harris 1976a, b; Jones *et al.*, 1976; Public Works Department, 1985; Roy and Peat, 1975; Yassini and Wright, 1988) which can be related to their foraminiferal assemblages and thus provide a basis for erecting general foraminiferal biotope models for coastal environments.

Physical Character of Lake Illawarra

A recent appraisal of the physical and chemical character of Lake Illawarra has been given in Yassini and Jones (1987). Lake Illawarra is a shallow elongate coastal lagoon situated 80km south of Sydney, N.S.W. It covers an area of about 34km^2 (Fig. 1) and fills a coastal depression scoured into the Late Permian Shoalhaven Group.

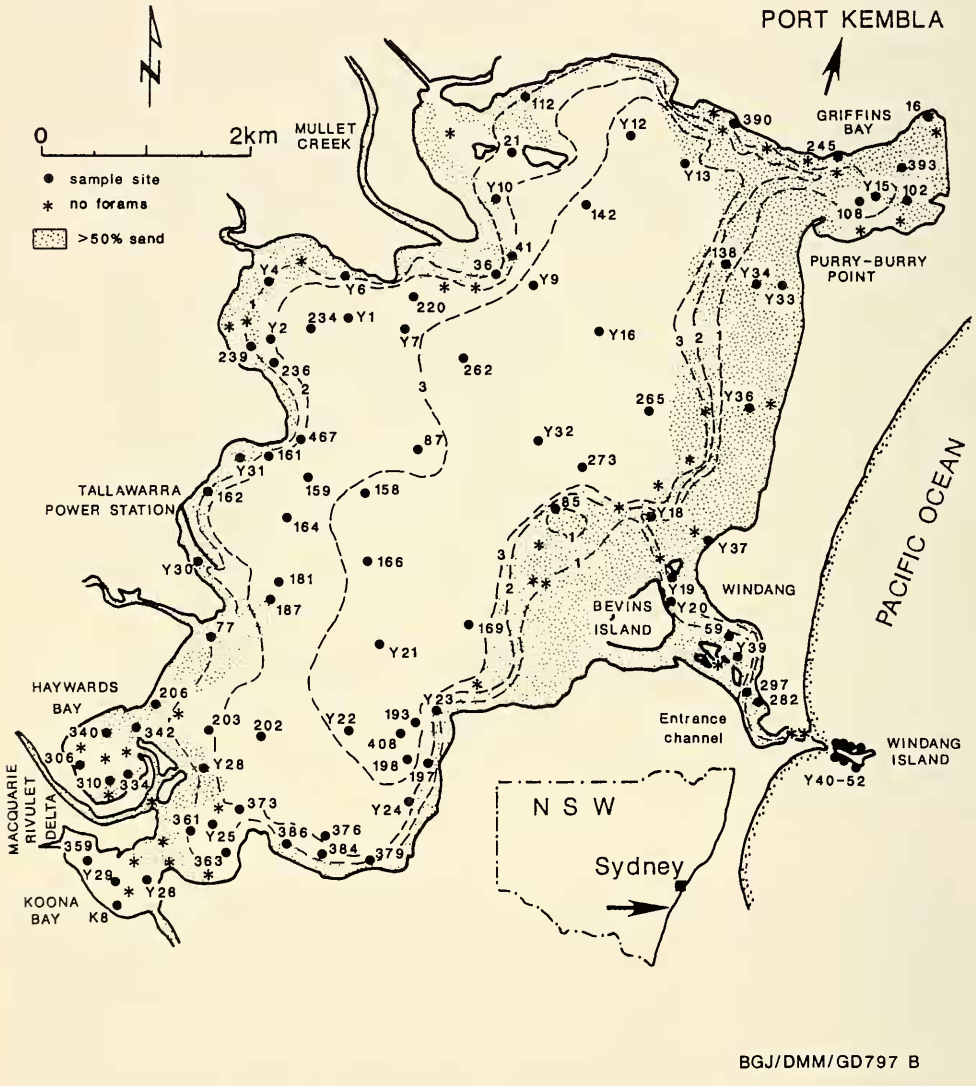

Fig. 1. Sample locations, water depths (in metres) and the distribution of sand-dominated substrates in Lake Illawarra.

The lagoon was formed during the last rise in ocean level some 6000-6500 years ago by the formation of a marine sand barrier north and south of Windang Island which impounded and flooded the former shallow marine embayment. The lagoon has a maximum depth of about 3.7m and an average depth of 1.9m (Roy and Peat, 1975). At present the lagoon water level is about 25-30cm above the mean ocean level and it is

separated from the ocean by a tidal channel 2.4km long, approximately 600m wide and up to 3.5m deep. The seaward end of the channel is continuously changing its position and shape, and heavy shoaling of the mouth occasionally causes complete closure of the lagoon.

Lake Illawarra has an average annual fresh water input of about 80 $\times$ 10^6m^3 (Ellis *et al.*, 1977). The tidal range along the landward margins of the lagoon is about 3-5cm increasing to 10-25cm near the tidal entrance channel. The average tidal exchange between the lagoon and the ocean is about 0.5 $\times$ 10^6m^3 giving a residence time of approximately 26-39 weeks for the lake water mass (Ellis *et al.*, 1977). Tidal currents are essentially limited to the entrance channel and currents within Lake Illawarra are mainly wind generated (Clarke and Eliot, 1984).

The average monthly lagoon surface water temperature ranges from 9°C in June to 29°C in February. At most times there is no significant difference between the surface and bottom water temperatures in the lagoon.

Sandy sediments within Lake Illawarra are confined to water depths shallower than 2m and they are most abundant along the eastern margin of the lake and around the Macquarie Rivulet and Mullet Creek deltas (Fig. 1). The central part of the lagoon has low relief with a depth of 2m to 3.7m and the sediments consist of dark grey silt and clay containing volatile organic matter (15-19%), iron monosulphides and faecal pellets.

Chemical Characteristics of Lake Illawarra

The salinity of the lagoon ranges from 16‰ to 40‰ depending on the balance between fresh water inflow, evaporation and the rate of tidal exchange. The salinity is within the normal estuarine range and, except during flood periods, low salinities are confined to stream mouths. Throughout the main body of the lagoon there is very little lateral or vertical variation in salinity values (<3‰, Ellis *et al.*, 1977) due to wind induced circulation and mixing of the water.

The mean pH of the surface layer in the lagoon varies between 7.3-8.3. In late winter, spring and summer, blooms of macro-algae increase the surface pH to almost 10 during the day but it returns to 7.3 at night. However, just below the water-sediment interface the connate water may be slightly acidic.

According to Ellis and Kanamori (1977) and the Electricity Commission of New South Wales (1982-1983) the concentration of dissolved oxygen in the surface layer of the lagoon during the day varies between 4-11mg/l. However, large fluctuations in dissolved oxygen concentrations between night and day occur in areas on the eastern side of the lagoon affected by algal blooms. For example, during one bloom in Griffins Bay the dissolved oxygen content ranged from a daytime maximum of 14mg/l to a night-time minimum of 1.5mg/l, with only 0.5mg/l of dissolved oxygen at the water-sediment interface. Salinity stratification and oxygen depletion of the bottom layer often occur after major flooding and periods of heavy rain (Gibbs, 1986). Nocturnal oxygen deficiencies are important in pH-Eh-related reactions in the bottom sediments, especially in the release of phosphorus to the water column and the denitrification of nitrate and nitrite.

As an enclosed saline coastal lagoon, with very limited tidal exchange and almost entirely surrounded by residential and industrial development, Lake Illawarra is subjected to continuous pollution. The pollutants are of three major categories: suspended solids, excess nutrients and heavy metals.

Suspended solids consist mainly of silt and clay which are removed from the catchment by erosion, especially river bank collapse, and are washed out of urban centres bringing some $100{,}000m^3$ of sediments annually into the lagoon. This can rise to $270{,}000m^3$ in years with major floods (Hean and Nanson, 1985). Flood tidal currents

bring an annual average 110,00m^3 of marine sand (Public Works Department, N.S.W., 1985) into the lagoon through the entrance channel. Fly-ash particles from Tallawarra Power Station (1952-present) and Port Kembla (1928-present) are also abundant in the lagoon sediments (Jones *et al.*, 1976). Coal-wash and slag deposited as back-fill in the lagoon catchment area have also contributed to the solid pollutants in the lagoon. Suspended solids increase turbidity, inhibit photosynthetic processes and increase the rapid infilling of the lagoon. The mean turbidity level of the lake for the period 1984-1985 was 6NTU.

Rural and urban drainage networks contribute large quantities of nitrogenous and phosphatic leachates to the lagoon and its bottom sediment and these contribute to the excess growth of macro-algae. During June 1985 an algal bloom produced 71,000 tonnes of macro-algae (Yassini, in prep.) and the subsequent decomposition of this mass caused an oxygen deficiency at the sediment-water interface allowing the production of H_2S and black iron monosulphides.

High localized concentrations of heavy metals in the top 25cm of lagoon sediments have been recorded by Jones *et al.* (1976), Roy and Peat (1975) and Ellis and Kanamori (1977). The main pollutants are zinc, lead and cadmium which were probably derived from the Dapto Smelting Works (1895-1906) and the Port Kembla industrial complex since 1928.

Benthic Flora and Fauna in Lake Illawarra

Both angiosperms and algae are important benthic floral constituents in the lagoon but are confined to water depths shallower than 2m since the high turbidity restricts light penetration to greater depths. On the shallow water sandy and muddy sandbanks along the tidal entrance channel and Windang Peninsula, around Mullet Creek and Macquarie Rivulet deltas and in Griffins and Koona bays four species of aquatic angiosperm (*Ruppia megacarpa* Masson, *Zostera capricorni* Aschers., *Halophila decipiens* Ostenfeld and *Halophila ovalis* (R.Br.) Hook. f.) are abundant. They are associated with green, red and brown algae, and several species of epiphytic blue-green and red algae occur on the leaves of *Zostera* and *Ruppia*. On rocky outcrops along the northern, western and southern shores of Lake Illawarra brown, green and red algae are the dominant floral constituents. Details of the algal flora are given in Yassini and Jones (1987).

The benthic invertebrate fauna in Lake Illawarra displays a low diversity but a high population density which is typical of estuarine systems. Polychaete worms and the molluscs *Tellina (Macoma) deltoidalis* (Lamarck), *Spisula trigonella* (Lamarck) and *Hydrobia buccinoides* (Hedley) form over 90% of macrobenthic biomass. Other constituents include additional molluscs, amphipods, isopods, cirripedes, ostracods, decapods, reptantes and tubellarids.

Foraminifers

For each of the 132 samples used in this study about 100cc of sediment was wet-sieved on a 200-mesh screen and the foraminifers were collected from 50cc of the washed residue, using conventional micro-palaeontological techniques. The foraminifers were not stained for live specimens since 2/3 of the samples came from a previous study (Jones *et al.*, 1976). The foraminifer classification (Appendix) used in this study conforms mainly to that of Loeblich and Tappan (1964, 1974, 1984). Additional references which were very useful for the specific identification of these southeastern Australian foraminifers include Albani (1974), Barker (1960), Brady (1884), Chapman and Parr (1937), Cushman (1932, 1933, 1942), Hermelin and Scott (1985), Kohl (1985),

Matoba (1970), McCulloch (1977, 1981), Murray (1975), Poag (1981), Seibold (1975) and Sidebottom (1912, 1913).

A total of 123 benthonic and 6 planktonic foraminiferal species have been recognized in Lake Illawarra, its tidal entrance channel and the intertidal zone surrounding Windang Island. All the benthonic species are shallow water forms and the vast majority of these species have been recorded from the diverse populations at Windang Island (85 species) and the entrance channel to the lagoon (89 species). Within Lake Illawarra 16 species have been recorded, mainly from the margins of the lagoon; only two species are common from the central part of the lagoon. Thirty nine samples from the lagoon and entrance channel contained no foraminifers. Distribution of all identified species is summarized in Tables 1 to 3 and in the Appendix. The total benthonic foraminiferal population density is indicated in Fig. 2.

TABLE 1

Samples containing only Ammonia beccarii *and* Cribrononion sydneyensis

Ammonia beccarii only	239, Y23, Y26, Y29, Y34, Y36
Ammonia: Cribrononion ratio	
>10:1	77, 162, 467, Y24
10:1 to 5:1	340, 376, 386, Y6, Y7
5:1 to 2:1	161, 164, 166, 187, 198, 203, 220, 236, 342, 361, 373, Y1, Y2, Y4, Y9, Y12, Y21
2:1 to 1:1	21, 87, 142, 158, 159, 169, 181, 202, 234, 262, 265, 384, Y16, Y22, Y25, Y31, Y32, Y39
<1:1	85, 112, 310, 359

The foraminiferal population within the lagoon is dominated by two of the three species of rotaliinids with more restricted distributions for the two species of miliolinids and eleven species of textulariinids.

The rotaliinids form the most abundant group in the lagoon and are represented by *Ammonia beccarii* and *Cribrononion sydneyensis* (Tables 1 and 2). A comparison of Figs 1 and 3 indicates that the two dominant species of rotaliinids in the lagoon constitute the entire foraminiferal population throughout almost all the deeper parts of the lagoon and its shallow embayments where the substrate is muddy. *Cribrononion sydneyensis* is confined to the deeper water areas (Fig. 4) whereas *Ammonia beccarii* is a very tolerant species occurring in almost all foraminiferal assemblages from the lagoon (Table 1), tidal channel and intertidal environments. It dominates at water depths of less than 1m where the substrate is sandy but it decreases in relative abundance from the lagoon towards the open ocean.

Textulariinids are most abundant around Mullet Creek and Macquarie Rivulet deltas, Griffins Bay and the tidal entrance channel (Fig. 5). Agglutinated foraminifers were mainly observed on sandy substrates but in Griffins Bay they were present in clay-rich sediment. While there is no distinct areal zonation of textulariinid species through the lagoon there is a distinct difference between the lagoon and the entrance channel-marine assemblage. The textulariinid species confined to the lagoon include *Protoschista findens*, *Miliammina fusca*, *Ammobaculites agglutinans*, *A. foliaceus*, *Texturalia porrecta*, *Eggerella australis* and *Trochammina inflata*. *Tritaxis conica* occurs both in the northern half of the lake and in the entrance channel and marine assemblages.

Miliolinids have a very restricted distribution within the lagoon system and are confined essentially to the entrance channel, the shallow zone along Windang Peninsula and isolated occurrences around delta mouths (Fig. 6). The two species, *Triloculina oblonga* and *Miliolinella subrotunda*, were found on sandy substrates with dense to

TABLE 2

Foraminiferal abundance in sediments from the Lake Illawarra area
(% per 100cc sample)

	Miliammina fusca	*Protoschista findens*	*Reophax* sp.	*Ammobaculites agglutinans*	*Ammobaculites foliaceus*	*Ammobaculites* sp.	*Ammotium cassis*	*Tritaxis conica*	*Trochammina inflata*	*Textularia porrecta*	*Eggerella australis*	*Miliolinella subrotunda*	*Triloculina oblonga*	*Cribrononion sydneyensis*	*Ammonia beccarii*	*Rotalia perlucida*
16	–	–	–	–	–	–	–	–	5.9	–	–	–	–	76.5	17.6	–
36	–	–	–	–	–	–	–	–	–	–	–	–	33.3	–	66.7	–
41	–	–	–	–	27.3	–	–	63.6	–	–	–	–	–	–	9.1	–
102	4.3	4.3	–	–	87.0	–	–	–	–	–	4.4	–	–	–	–	–
108	–	–	–	–	–	–	–	33.3	–	–	–	–	–	33.3	33.3	–
138	–	–	–	–	0.4	–	–	0.9	–	–	26.8	–	–	–	71.4	–
206	–	–	–	5.1	–	–	–	–	–	–	–	–	–	44.3	50.6	–
245	6.3	2.1	–	–	2.1	–	–	–	83.3	–	–	–	–	–	–	6.3
306	9.9	12.4	–	–	43.2	–	–	–	24.7	–	–	–	–	2.5	4.9	2.5
334	–	–	–	–	92.9	–	–	–	–	–	–	7.1	–	–	–	–
363	–	–	–	–	3.3	–	–	–	–	–	–	–	–	30.0	66.7	–
379	–	1.0	–	–	1.0	–	–	–	–	–	–	–	–	40.6	57.3	–
390	–	–	–	–	–	–	–	–	–	–	–	–	14.7	85.3	–	–
393	–	2.9	–	2.9	–	–	–	–	–	–	–	–	–	13.3	80.9	–
408	–	–	–	–	–	–	–	–	–	–	–	0.4	–	42.4	57.2	–
Y10	–	16.7	–	–	–	11.1	–	27.8	5.6	–	22.2	–	–	–	16.7	–
Y13	–	3.2	3.2	1.3	–	–	–	2.0	–	16.1	16.1	–	–	12.9	45.2	–
Y15	–	–	–	–	12.5	–	–	–	–	–	–	–	–	–	87.5	–
Y28	–	–	–	–	19.4	–	–	–	–	–	–	38.7	–	–	41.9	–
Y30	–	–	–	–	–	–	0.8	–	–	2.3	19.2	–	–	0.8	76.9	–
Y33	1.4	–	–	–	–	–	–	1.4	–	–	–	–	27.8	–	69.4	–
Y37	–	–	–	–	–	–	–	–	–	–	–	37.5	–	25.0	37.5	–
K8	–	–	–	–	–	–	–	–	–	–	–	1.0	–	25.3	73.7	–

TABLE 3

Number frequency distribution of Foraminifera around Windang Island and in the entrance channel

	Entrance channel								Windang Island				
	59	273	282	297	Y18	Y19	Y20	Y39	Y41	Y42	Y44	Y46	Y52
Haplophragmoides canariensis	–	–	–	–	–	–	–	–	13	16	–	–	20
Tritaxis conica	–	–	4	–	–	5	–	2	2	–	–	–	–
Textularia candeiana	–	–	–	–	–	–	–	–	–	30	4	–	20
Textularia porrecta	–	–	1	–	–	–	–	–	–	–	–	–	–
Textularia sagittula	–	–	–	–	–	–	2	–	4	10	–	5	15
Textularia sp. I	–	–	–	–	–	–	–	–	–	–	–	–	4
Textularia sp. II	–	–	–	–	–	–	–	–	50	–	–	–	38
Eggerella subconica	–	–	–	–	–	–	–	–	2	–	–	–	28
Gaudryina convexa	–	–	–	–	1	–	1	–	–	5	–	–	13
Spiroluculina antillarum	–	–	–	–	–	–	–	–	10	–	–	–	14
Spiroloculina communis	–	–	–	–	–	–	5	–	–	–	–	–	3
Milliolinella baragwanathi	–	–	–	–	–	–	6	–	8	5	–	10	41
Milliolinella circularis	–	–	–	–	–	–	3	–	10	5	–	–	80
Milliolinella circularis subsp. nov.	–	–	–	–	–	–	–	–	–	–	–	–	6
Miliolinella subrotunda	–	–	1	–	–	–	–	–	–	1	–	–	–
Pyrgo subglobulus	–	–	–	–	–	2	–	–	–	–	–	–	1
Quinqueloculina granulocostata	–	–	–	–	–	–	–	–	1	–	–	–	–
Quinqueloculina poeyana	1	–	1	–	8	3	–	–	6	–	–	–	28
Quinqueloculina pseudoreticulata	–	–	–	–	–	2	–	–	8	5	3	–	8
Quinqueloculina seminula	–	–	4	–	–	–	–	–	–	–	–	–	36
Quinqueloculina subpolygona	–	–	–	–	–	15	10	–	10	10	3	52	184
Quinqueloculina tasmanica	–	–	–	–	–	–	–	–	2	–	–	–	–
Quinqueloculina tropicalis	–	–	–	–	–	–	–	–	3	–	–	–	5
Quinqueloculina sp. nov.	–	–	–	–	–	–	–	–	–	–	–	–	12
Triloculina oblonga	–	–	–	–	1	–	–	1	12	–	–	–	–
Triloculina tricarinata	–	–	–	–	–	–	–	–	1	–	–	–	–
Triloculina trigonula	–	–	–	–	1	–	4	–	–	10	10	–	34
Guttulina pacifica	–	–	1	–	–	5	–	–	–	–	–	–	8
Guttulina sp. I	–	–	–	–	–	–	–	–	–	3	–	–	–
Guttulina sp. II	–	–	–	–	–	1	–	–	–	–	–	–	1
Sigmoidella elegantissima	–	–	–	–	–	2	–	–	1	–	–	–	–
Amphicoryna scalaris	–	–	–	–	1	1	1	–	–	–	–	–	–
Bolivinella folia	–	–	–	–	–	1	–	–	–	–	–	–	–

TABLE 3 (continued)

	Entrance channel								Windang Island				
	59	273	282	297	Y18	Y19	Y20	Y39	Y41	Y42	Y44	Y46	Y52
Fissurina fasciata carinata	–	–	–	–	–	–	3	–	3	–	–	–	21
Fissurina lacunata	–	–	–	–	–	3	–	–	1	–	–	–	9
Fissurina marginatoperforata	–	–	–	–	–	1	–	–	–	–	–	–	–
Fissurina cf. *subquadrata*	–	–	–	–	–	–	–	–	–	–	–	–	2
Fissurina sulcata	–	–	–	–	–	1	–	–	–	–	–	–	–
Fissurina sp. I	–	–	1	–	–	–	–	–	–	–	–	–	–
Fissurina sp. II	–	–	–	–	–	1	–	–	–	–	–	–	–
Lagena acuticosta	–	–	–	–	–	–	–	–	–	–	–	–	1
Lagena crenata	–	–	1	–	–	–	–	–	–	–	–	–	–
Lagena gracillima	–	–	–	–	–	–	–	–	–	–	–	–	3
Lagena cf. *gracillima*	–	–	–	–	–	1	–	–	–	–	–	–	–
Lagena cf. *implicata*	–	–	–	–	–	1	–	–	1	–	–	–	–
Lagena semilineata	–	–	–	–	–	1	–	–	–	–	–	–	–
Lagena cf. *semistriata*	–	–	–	–	–	1	–	–	–	–	–	–	–
Lagena subacuticosta	–	–	1	–	–	–	–	–	–	–	–	–	2
Lagena sulcata	–	–	1	–	–	–	–	–	–	–	–	–	2
Planularia patens	–	–	1	–	–	–	–	–	–	–	–	–	–
Oolina lineata	–	–	–	–	–	2	–	–	–	–	–	–	–
Oolina striatopunctata gemma	–	–	–	–	–	4	–	–	–	–	–	–	–
Oolina sp. I	–	–	–	–	–	1	–	–	–	–	–	–	–
Oolina sp. II	–	–	1	–	–	–	–	–	–	–	–	–	–
Bolivina compacta	–	1	–	–	–	–	–	–	–	–	–	–	–
Bolivina doniezi	–	–	–	–	–	1	–	–	–	–	–	–	–
Bolivina perforatum	–	–	–	–	–	10	–	–	–	–	–	–	–
Bolivina pseudoplicata	–	–	–	–	–	3	–	–	3	–	–	–	–
Bolivina robusta	–	–	–	–	–	3	–	–	2	–	–	–	–
Bolivina sp.	–	–	3	–	–	–	–	–	–	–	–	–	–
Brizalina alata	–	–	1	–	–	–	–	–	–	1	–	–	2
Brizalina striatula	–	–	2	–	–	–	1	–	–	1	–	–	–
Bulimina elongata subulata	–	–	1	–	–	–	–	–	–	–	–	–	–
Bulimina marginata	–	–	–	–	–	1	–	–	–	–	–	–	–
Reussella spinulosa	–	–	–	–	–	2	–	–	–	–	–	–	2
Buliminoides gracilis	–	–	–	–	–	5	1	–	2	1	–	–	10
Buliminoides williamsonianus	–	–	–	–	–	3	–	–	–	–	–	–	13

TABLE 3 (continued)

	Entrance channel								Windang Island				
	59	273	282	297	Y18	Y19	Y20	Y39	Y41	Y42	Y44	Y46	Y52
Uvigerina bassensis	–	–	2	–	3	–	–	–	3	2	–	–	5
Uvigerina cf. *peregrina*	–	–	–	–	–	2	–	–	–	–	–	–	–
Angulodiscorbis quadrangularis	–	–	–	–	–	–	–	–	3	3	–	–	12
Glabratella australensis	–	–	–	–	1	10	–	–	25	10	3	22	86
Glabratella cf. *parri*	–	–	–	–	–	2	–	–	–	–	–	–	–
Glabratella patelliformis	–	–	–	–	–	–	–	–	15	10	–	–	–
Glabratella pulvinata	–	–	–	–	–	–	–	–	2	–	–	–	15
Glabratella tabernacularis	–	–	–	–	–	–	–	–	20	18	–	–	6
Glabratella sp. I	–	–	–	–	–	–	–	–	–	–	–	–	3
Glabratella sp. II	–	–	–	–	–	3	–	–	–	–	–	–	–
Baggina phillippinensis	–	–	–	–	1	–	–	–	6	–	2	–	12
Buccella pustulosa	–	–	–	–	–	–	–	–	–	–	–	–	13
Discorbinella bertheloti	–	–	–	–	–	5	–	–	4	–	–	–	–
Discorbinella planoconcava	–	–	–	–	–	–	–	–	–	1	–	–	–
Lamellodiscorbis dimidiatus	6	–	59	30	14	–	35	3	280	100	40	10	100
Patellinella inconspicua	–	–	–	–	–	–	–	–	16	4	–	–	8
Planulinoides bivoncavus	–	–	2	–	–	–	–	–	1	–	–	–	–
Rosalina anglica	–	–	–	–	2	15	–	–	230	220	–	10	180
Rosalina australis	–	–	1	–	10	10	8	–	170	50	–	–	90
Rosalina bradyi	–	–	–	–	–	50	–	–	230	80	3	9	60
Lamarckina sp.	–	–	–	–	–	2	–	–	–	–	–	–	–
Cymbaloporetta bradyi	–	–	–	–	–	3	–	–	10	2	20	–	78
Acervulina inhaerens	–	–	–	–	2	5	3	–	5	10	–	–	29
Planorbulina mediterranensis	–	–	–	–	2	5	3	–	5	10	–	–	29
Cribrononion sydneyensis	–	37	–	–	–	–	–	–	–	–	–	–	–
Elphidium advenum	–	–	4	–	1	–	–	–	–	10	–	–	–
Elphidium argenteus	–	–	–	–	–	–	–	–	–	–	–	–	39
Elphidium crispum	–	1	5	–	50	70	20	3	100	10	–	–	130
Elphidium depressulum	–	–	–	–	–	10	–	–	20	–	–	22	31
Elphidium jenseni	–	–	2	–	2	12	6	–	60	20	10	–	–
Elphidium macellum	–	1	–	–	5	20	10	–	130	20	–	18	180
Elphidium sp.	–	–	–	–	–	3	–	1	–	–	–	–	–
Parrellina imperatrix	–	–	2	4	–	–	4	1	–	3	–	–	24
Nonion depressulus	–	–	–	–	–	3	–	–	–	–	–	–	–

TABLE 3 (concluded)

	Entrance channel								Windang Island				
	59	273	282	297	Y18	Y19	Y20	Y39	Y41	Y42	Y44	Y46	Y52
Nonionella auris	–	1	–	–	–	10	–	–	10	10	–	–	25
Ammonia beccarii	–	70	–	–	50	80	35	2	20	10	5	–	20
Rotalia perlucida	–	–	–	–	–	–	–	–	–	–	–	–	8
Cibicides cygnorum	–	–	13	4	10	–	10	2	40	30	5	–	86
Cibicides refulgens	–	–	–	–	–	–	–	–	–	–	–	–	30
Dyocibicides biserialis	–	–	–	–	5	–	4	–	10	10	–	–	60
Anomalina nonionoides	–	–	13	1	2	5	–	–	–	–	–	–	–
Patellina corrugata	–	–	–	–	–	–	–	–	–	–	–	–	18
Spirillina denticulata	–	–	–	–	–	2	–	–	–	–	–	–	–
Spirillina inaequalis	–	–	–	–	–	–	–	–	–	4	–	–	–
Spirillina tuberculata	–	–	–	–	–	1	–	–	–	–	–	–	–
Spirillina vivipara	–	–	10	–	–	–	–	–	–	–	–	–	34
Spirillina sp.	–	–	–	–	–	1	–	–	–	–	–	–	–
Globigerina bulloides	–	–	1	–	2	3	2	–	10	–	–	–	–
Globigerina sp.	–	–	–	–	–	–	–	–	–	–	–	–	10
Globigerinoides ruber	–	–	–	–	–	5	3	–	10	–	4	–	10
Globoquadrina dutertrei	–	–	–	–	–	2	5	–	–	–	–	–	–
Orbulina universa	–	–	–	–	–	1	2	–	–	–	–	–	–
Pulleniatina obliqueloculata	–	–	–	–	2	–	–	–	–	–	–	–	–
Globorotalia hirsuta	–	–	–	–	–	1	–	–	3	–	–	–	–
Globorotalia (Turborotalia) inflata	–	2	2	–	3	–	2	2	4	–	1	–	4

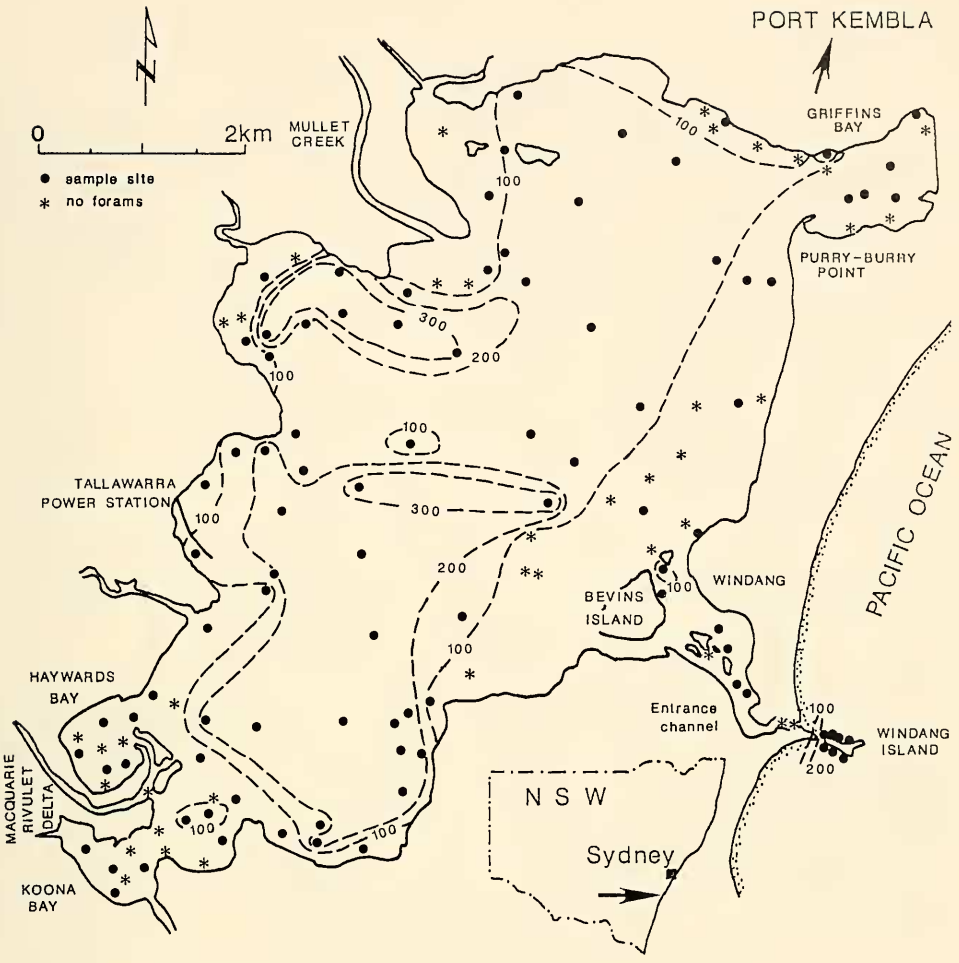

Fig. 2. Total number of benthonic foraminifers in 100cc of sediment at each sample site.

moderate sea grass coverage in the northern and southern parts of the lagoon respectively (thus accounting for their poor correlation with the more uniformly distributed textulariinid species in the sandy lagoon margin sediments — Fig. 7).

The entrance channel and Windang Island samples contain a mixed assemblage of intertidal and subtidal benthonic foraminifers and a few planktonic species (Table 3; Fig. 8). This is a typical intertidal population which is similar to many other areas on the N.S.W. coast (e.g., Albani, 1968, 1979; Albani and Johnson, 1976).

Foraminifers from a constant volume of each sample from the area studied were subjected to R-mode and Q-mode multivariate analysis. Based on similarity levels and grouping of samples (Figs 7-8) the following four distinct assemblages (Fig. 9) were recognized within the studied area.

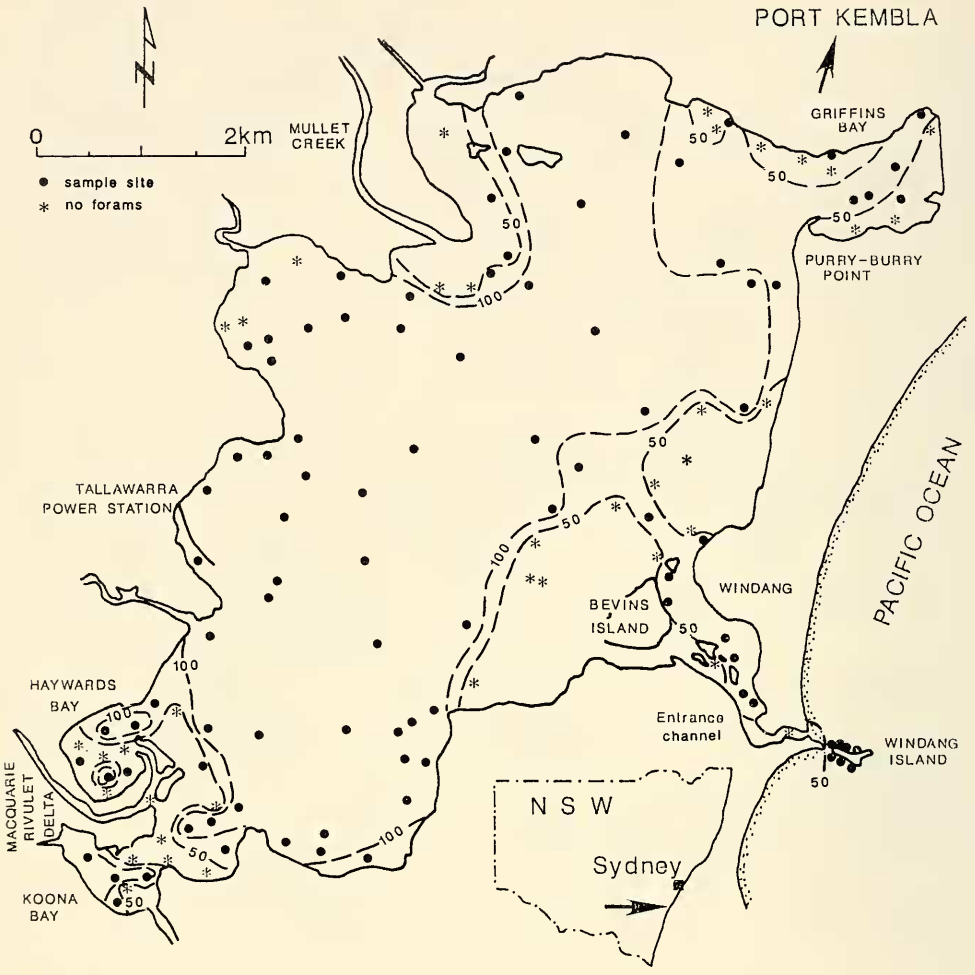

Fig. 3. Distribution of rotaliinids in Lake Illawarra (in percent).

Assemblage I

This assemblage (27 samples) occurs in the deepest parts of the lake on a silty clay substrate. It is dominated by *Ammonia beccarii* (52.7%) and *Cribrononion sydneyensis* (43.9%) with subordinate *Triloculina oblonga* (3.0%). Another six species of textulariinids and miliolinids comprise less than 0.4% of the total fauna in this assemblage and mainly occur in samples from close to the lake margin.

Assemblage II

The 37 samples comprising Assemblage II have even more limited foraminiferal diversity. It is dominated by *Ammonia beccarii* (83.2%) and *Cribrononion sydneyensis* (16.4%). Only two other species occur in this assemblage, namely *Ammobaculites foliaceus* (0.4%) and *Miliolinella subrotunda* (0.03%).

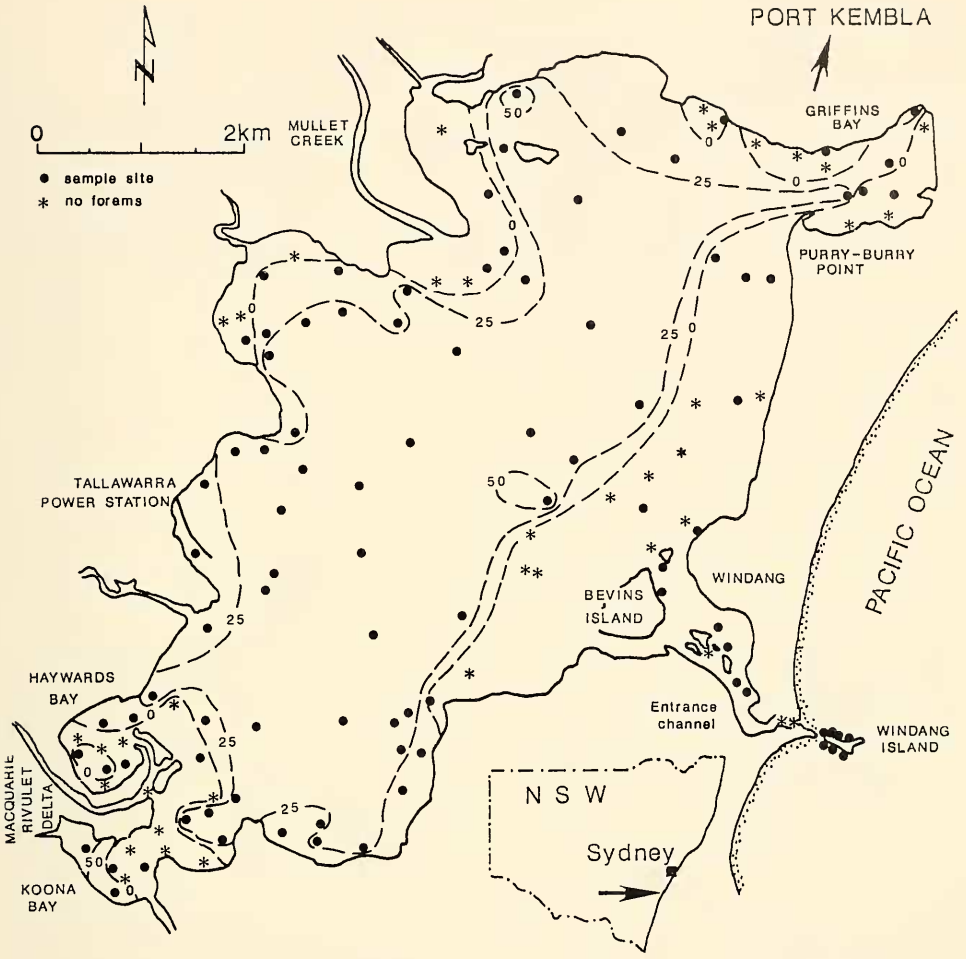

Fig. 4. Distribution of *Cribrononion sydneyensis* in Lake Illawarra (in percent).

Assemblage III

Assemblage III occurs in the four areas around the margins of the lake where nutrient supplies are greatest (that is, adjacent to the tidal entrance channel), Macquarie Rivulet and Mullet Creek deltas and Griffins Bay. In all these areas the substrate is predominantly sand and the flora is dominated by *Zostera capricorni* Aschers. The 15 samples are dominated by textulariinids (10 species, 49.6%), rotalids (6 species, 44.8%) and *Miliolinella subrotunda* (5.6%). The main textulariinid species are *Ammobaculites foliaceus* (18.2%), *Tritaxis conica* (10.5%), *Trochammina inflata* (7.6%) and *Eggerella australis* (6.3%) and the two dominant rotaliinids are the lagoonal *Ammonia beccarii* (33.3%) and *Cribrononion sydneyensis* (10.5%).

Assemblage IV

The fourth assemblage consists of a mixture of predominantly marine foraminifers (Fig. 8), some of which represent a life assemblage. Approximately half of the species

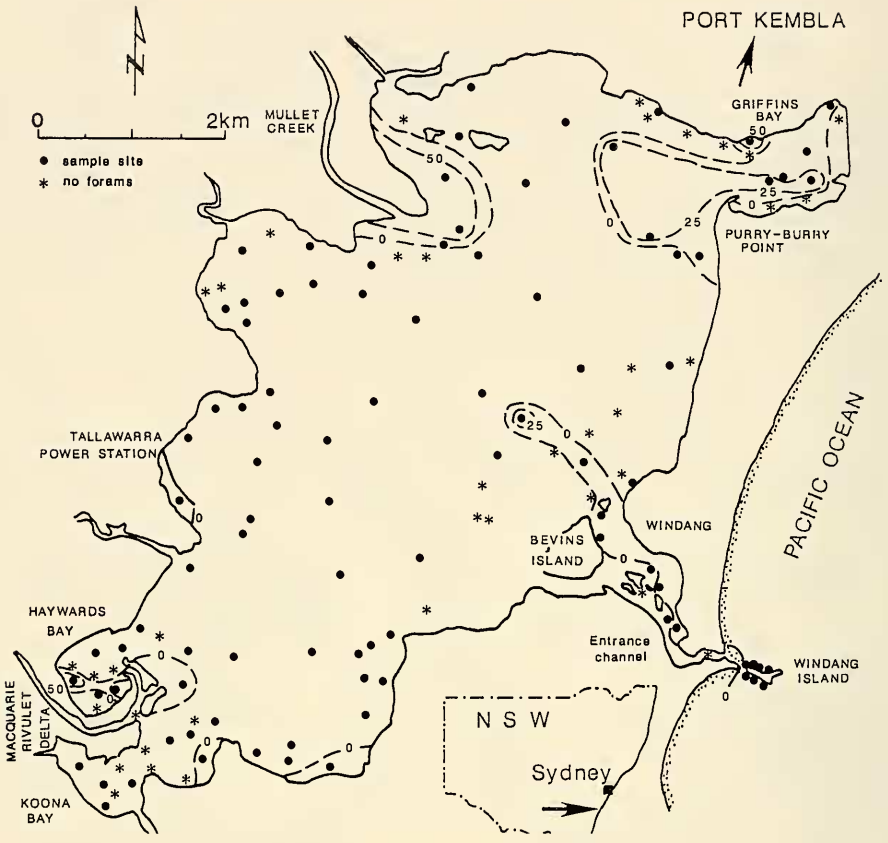

Fig. 5. Distribution of textulariinids in Lake Illawarra (in percent).

probably have been reworked from subtidal environments into Assemblage IV and are only represented by a few specimens. The tidal entrance channel and Windang Island areas have 55 species in common and of these 35 species probably represent live species based on more than 8 specimens being present at a sample site.

The most abundant species constituting an average of 70% of the population at each site in Assemblage IV are:

	Mean number of individuals	Mean % abundance at each location
Lamellodiscorbis dimidiatus	56.5	27.1
Rosalina anglica	54.8	5.0
Elphidium crispum	40.7	9.0
Rosalina bradyi	36.0	3.9
Elphidium macellum	31.9	3.6
Rosalina australis	27.6	2.8
Quinqueloculina subpolygona	23.7	4.6
Ammonia beccarii	18.8	7.1
Cibicides cygnorum	16.7	4.6
Glabratella australensis	13.1	2.2

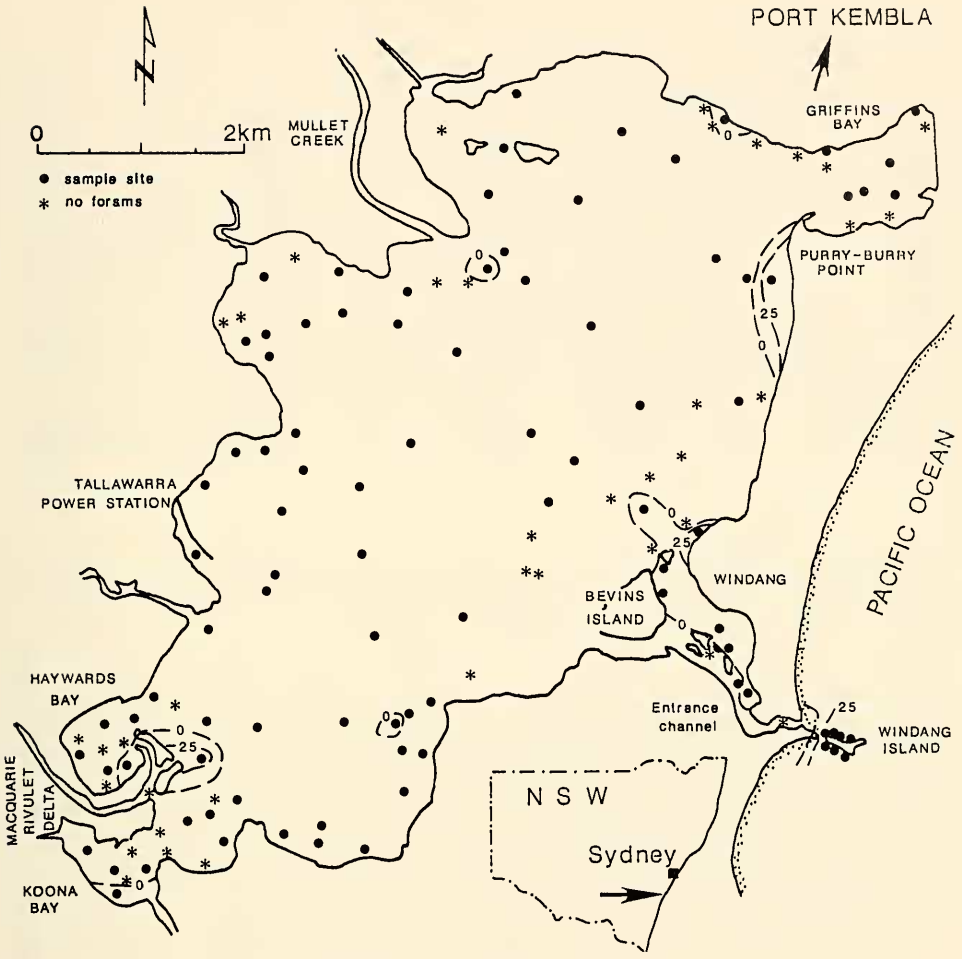

Fig. 6. Distribution of miliolinids in Lake Illawarra (in percent).

The mixed nature of this tidal assemblage is clearly illustrated in Fig. 8 and consists of lagoonal, intertidal and subtidal species forming a complex thanatocoenose. Minor subdivisions of this assemblage are dependent upon preferential association with particular algal species, especially coralline algae and *Zonaria*.

Lake Illawarra Foraminiferal Communities

The assemblages in Lake Illawarra and its tidal entrance channel are very typical of estuarine lagoons with restricted tidal circulation (e.g., Apthorpe, 1980; Cotter, 1980; Michie, 1982; and Murray, 1973). The distribution pattern and species diversity of foraminifers in the Lake Illawarra area can be used as a basis for distinguishing mud- and sand-dominated lagoonal environments from tidal channel and more open estuarine bay environments such as Broken Bay (Albani, 1978) and Botany Bay (Albani, 1981).

The foraminiferal assemblages in Lake Illawarra can be directly related to the floral communities with the greatest diversity of foraminifers occurring in the seagrass beds

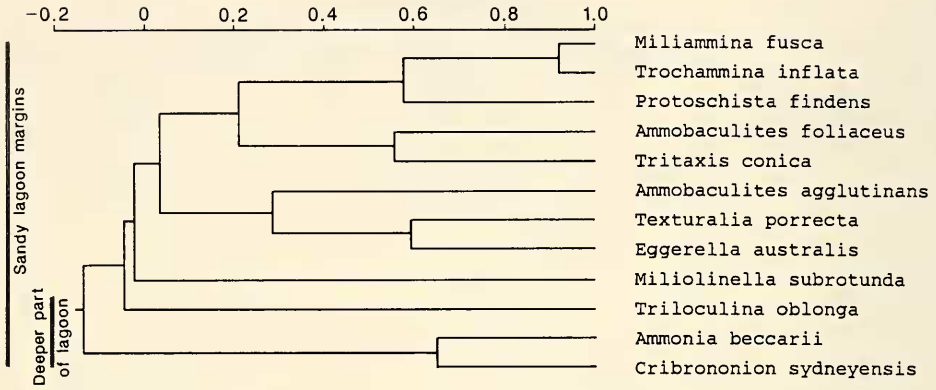

Fig. 7. R-mode cluster dendrogram for species occurring at more than two localities within Lake Illawarra. *Ammonia beccarii* and *Cribrononion sydneyensis* form a distinct group characteristic of deeper water or silty sediments whereas the textulariinids characterize shallow sandy substrates.

where there is relatively low turbidity, a low mud content and an abundant oxygen supply. However, these areas are subject to wider fluctuations in pH and Eh, as well as moderate variations in salinity and temperature, compared with the main body of the lagoon where circulation is less restricted. Foraminiferal faunas on the lagoon margins are dominated by typical euryhaline eurythermal lagoonal species such as *Cribrononion sydneyensis*, *Ammonia beccarii*, *Miliolinella subrotunda* and textulariinids (Fig. 7; Table 2). In the higher energy, wave-influenced margins of the shallow lagoon sandflats the substrate is too mobile for colonization by and preservation of foraminifers and most samples in these regions were barren.

In the deeper portion of Lake Illawarra and in sheltered shallower regions mud is the dominant substrate and, together with the relatively high turbidity, prevents the establishment of seagrass beds. In these areas the foraminiferal diversity is very low (only one or two dominant rotaliinid species) but the population densities range up to 350 specimens per 100cc of sample, the highest density in the lagoon system (Fig. 2). A few shallow water areas within the muddy facies have large accumulations of decaying organic matter (e.g., parts of Griffins, Haywards and Koona bays) resulting in anaerobic bottom conditions which inhibit benthonic foraminifers colonizing these areas. This assemblage therefore shows a great range in foraminiferal abundance which is dependent on a number of environmental factors, not just salinity variation.

The tidal entrance channel to the lagoon is characterized by a very diverse total foraminiferal population with a mixed assemblage of both marine and lagoonal species. Few foraminiferal species live in the mobile sandy tidal channel, which contains a partially abraded mixed marine and estuarine fauna, whereas the seagrass banks along the channel margins support a diverse assemblage with strong shallow marine affinities. The only major distinction between this facies and intertidal open marine facies is the greater abundance of reworked lagoonal species in the tidal channel (although they form less than 2% of the foraminifera population in the channel area).

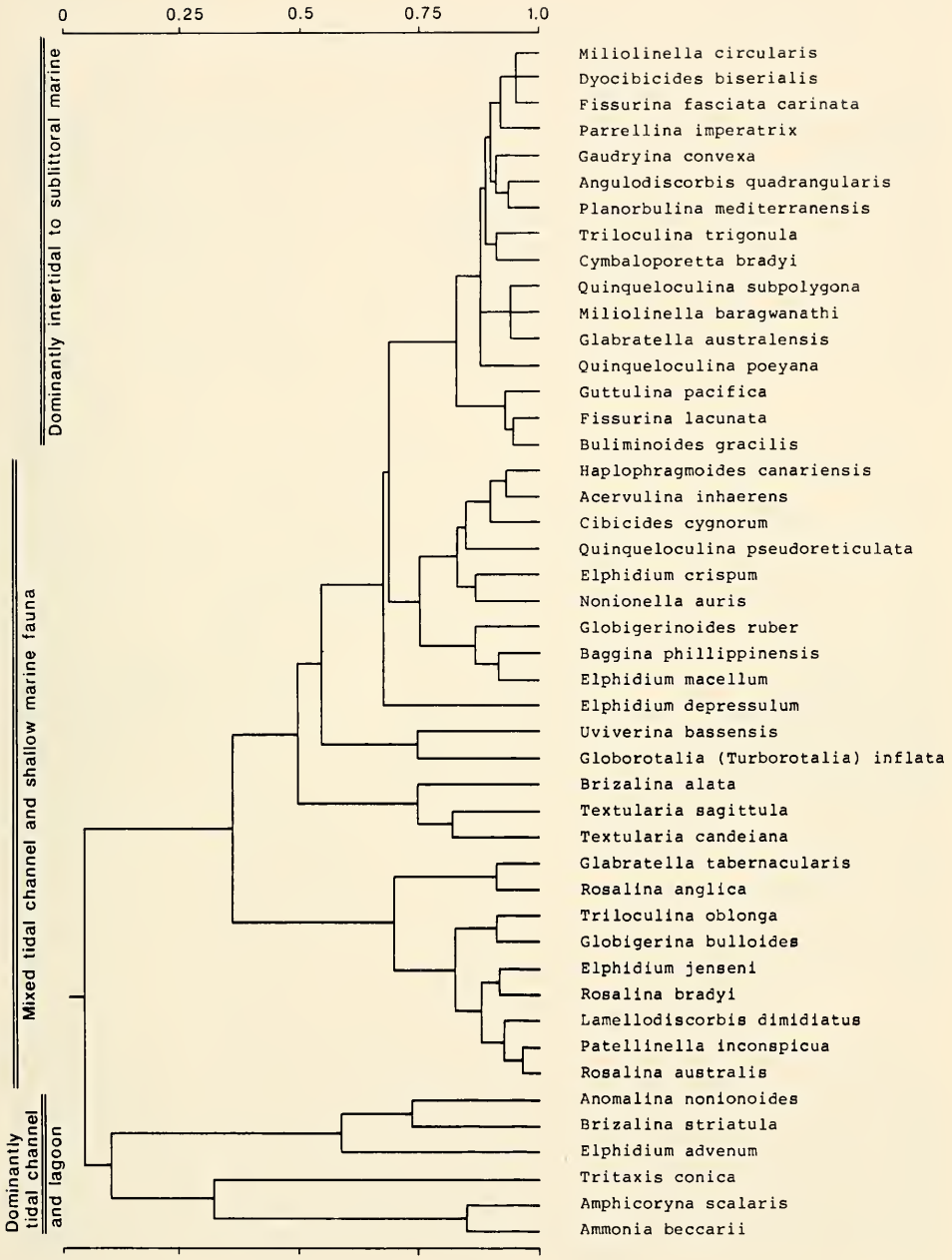

Fig. 8. R-mode cluster dendrogram for species occurring at more than two localities in the tidal channel and around Windang Island. A closely correlated, dominantly marine fauna shows strong similarity to the mixed assemblage of the tidal channel whereas these assemblages show very poor correlation with the lagoonal to tidal channel group.

Fig. 9. Foraminiferal assemblages in Lake Illawarra defined by Q-mode cluster analysis.

Estuarine Foraminiferal Communities in N.S.W.

Distribution patterns and species diversity of foraminiferal faunas in the estuarine environments along the coast of New South Wales show two distinct ecological situations. The first is a low diversity and low to moderate population density model, typified by examples of shallow coastal lagoons such as Lake Illawarra, Narrabeen Lagoon, Tuggerah Lake and Lake Macquarie. The second type exhibits high-diversity and medium-density populations in drowned valleys and estuaries, illustrated by example of Broken Bay, Botany Bay and Jervis Bay. In both models the mixing rate of fresh and saline water masses, and salinity fluctuations, play a determinant role in the faunal distribution. The dynamic setting of the environment and the mobility of the substrate are the main factors controlling faunal distributions within the different salinity zones.

Sand-barrier Coastal Lagoon Foraminiferal Community

In N.S.W. lagoons such as Lake Illawarra, Narrabeen Lagoon and Tuggerah Lake the fine-grained sediment in the main body of the lagoon supports a dominant assem-

blage of *Ammonia beccarii* and *Cribrononion sydneyensis* together with a few arenaceous species such as *Eggerella australis*, *Textularia porrecta* and *Ammobaculites agglutinans*. Similar assemblages were also observed in Lake Victoria and the Gippsland lake system (Apthorpe, 1980), and in Hardy Inlet, Western Australia (Quilty, 1976). The seagrass beds in the peripheral zone around the margin of these lagoonal environments supports a fauna dominated by arenaceous forms such as *Trochammina inflata*, *Ammobaculites agglutinans* and *Eggerella australis* and a few species of Miliolidae (e.g., *Miliolinella subrotunda* and *Triloculina oblonga*).

The tidal channels connecting these lagoons to the open ocean contain a mixture of reworked forms from the nearby oceanic intertidal zone and the lagoon proper. In Lake Illawarra, 82 species were encountered in the seagrass beds along the banks of the inlet channel where the energy level is more reduced. In the middle of the channel the mobile sandy substrate contains only a minor abraded and reworked microfauna. Hardy Inlet contained 42 species in the connection channel (Quilty, 1976). In Narrabeen Lagoon 38 species were identified in the inlet channel while the main body of the lagoon contains only 12 species (Yassini, in prep.).

Tidal Estuary Foraminiferal Community

In the second estuarine ecological type, where tidal exchange of the watermass is rapid, the diversity and density of the foraminiferal population gradually decreases from the mouth of the bay towards the higher reaches of the estuary.

In Broken Bay, Albani (1978) recorded 181 species of benthonic foraminifers along 40km of estuary. The density of the foraminifer population was low both at the upstream end of the estuary and at the outer entrance of the estuary. Upstream in the non-tidal section of the estuary, where the fresh and saline water masses meet and oligohaline conditions prevail, only a few arenaceous foraminifers were found. In the main section of the estuary where there is little change in salinity, the fauna is mostly dominated by Miliolidae (31 species) and Nodosariidae (23 species). Where the estuary has a restricted oceanic connection, foraminifer populations decrease in diversity due to the mobility of the sandy substrate during each tidal cycle.

In the Port Hacking estuary, Albani (1968) recorded 119 species of foraminifers along a 10.4km stretch of the estuary. In the weakly-tidal fluvial-dominated section of the estuary only 15 species were found. A maximum diversity of 108 species was found in the main tide-dominated section of the estuary where Miliolidae were represented by 18 species (only 15% of the total fauna). Based on both foraminifer and ostracod distributions, the ecological model in Port Hacking is intermediate between a typical open oceanic bay and a lagoon (Yassini and Wright, 1988).

Open Ocean Foraminiferal Communities

In the upper intertidal zone along the foreshore of Windang Island near the oceanic end of the entrance channel to Lake Illawarra, the foraminiferal density and diversity are typical of an open ocean embayment environment. In the zone 85 species were recorded with Nodosariidae (8 species) and Miliolidae (16 species) forming a prominent component of the foraminiferal assemblage. Foraminiferal assemblages in the open ocean are controlled by the substrate, energy and depth of the environment but a discussion of these facies is beyond the scope of this paper.

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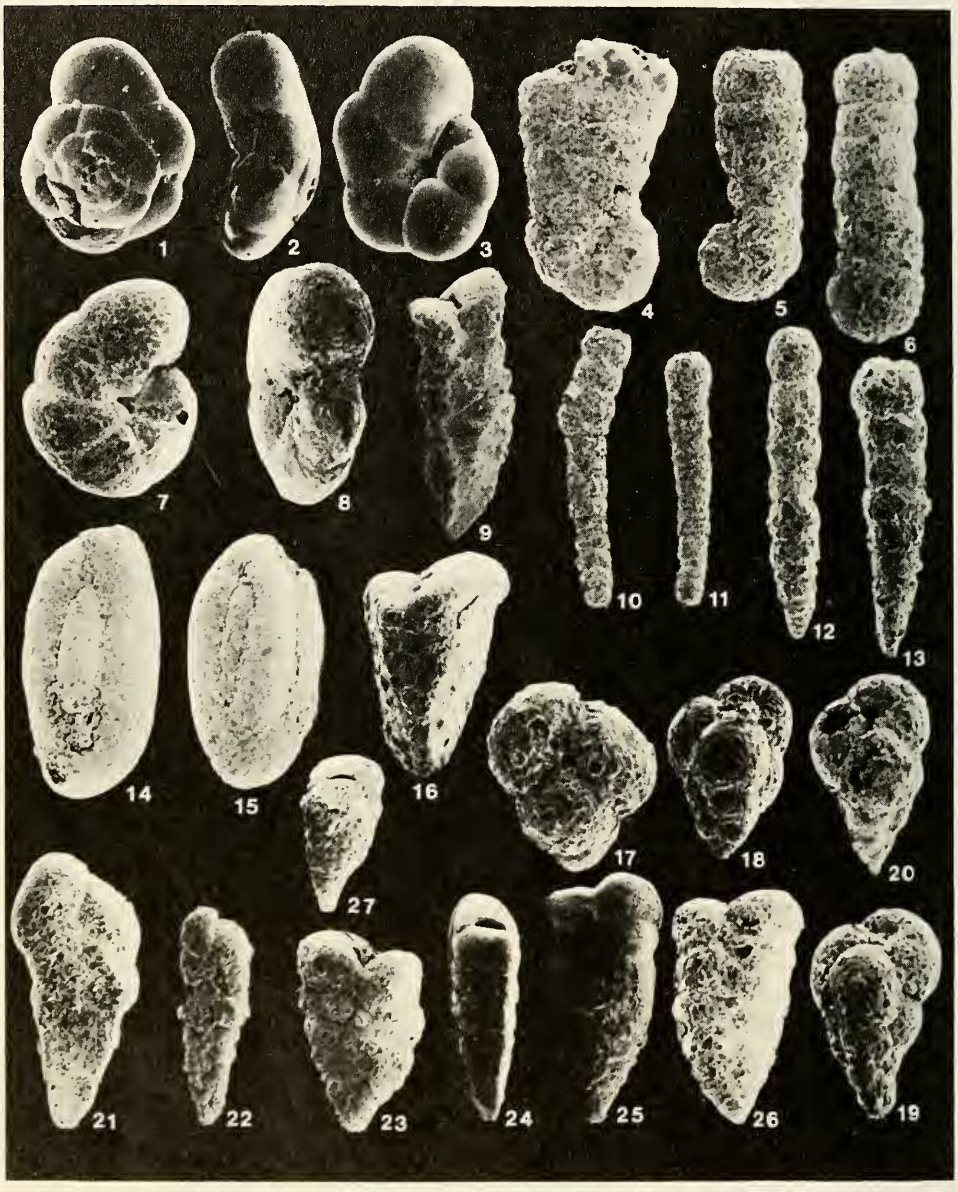
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Fig. 10. **1-3,** *Trochammina inflata* Sample 245, Lake Illawarra. x54 Spiral, apertural and umbilical views; **4,** *Ammobaculites foliaceus* Sample Y15, Lake Illawarra. x50 Spiral view; **5,** *Ammobaculites agglutinans* Sample Y13, Lake Illawarra. x 55 Spiral view; **6,** *Ammobaculites* sp. Sample Y10, Lake Illawarra. x50 Spiral view; **7-8,** *Haplophragmoides canariensis* Sample Y52, Windang Island. x47. Umbilical and apertural views; **9, 16,** *Gaudryina convexa* Sample Y52, Windang Island. x25, x44 Lateral views; **10-11,** *Protoschista findens* Sample 306, Lake Illawarra. x50 Lateral views; **12-13,** *Reophax* sp. Sample Y13, Lake Illawarra. x75 Lateral views; **14-15,** *Miliammina fusca* Sample 245, Lake Illawarra. x71 Lateral views; **17-20,** *Eggerella australis* Sample 138, Lake Illawarra. x80 Lateral and apertural views; **21,** *Textularia* sp. 1 Sample Y52, Windang Island. x78 Lateral view; **22,** *Textularia porrecta* Sample Y30, Lake Illawarra. x50 Lateral view; **23, 27,** *Textularia candeiana* Sample Y42, Windang Island. x57, x60 Lateral and apertural views; **24, 25,** *Textularia sagittula* Sample Y52, Windang Island. x38 Apertural and lateral views; **26,** *Textularia* sp. II Sample Y52, Windang Island. x48 Lateral view.

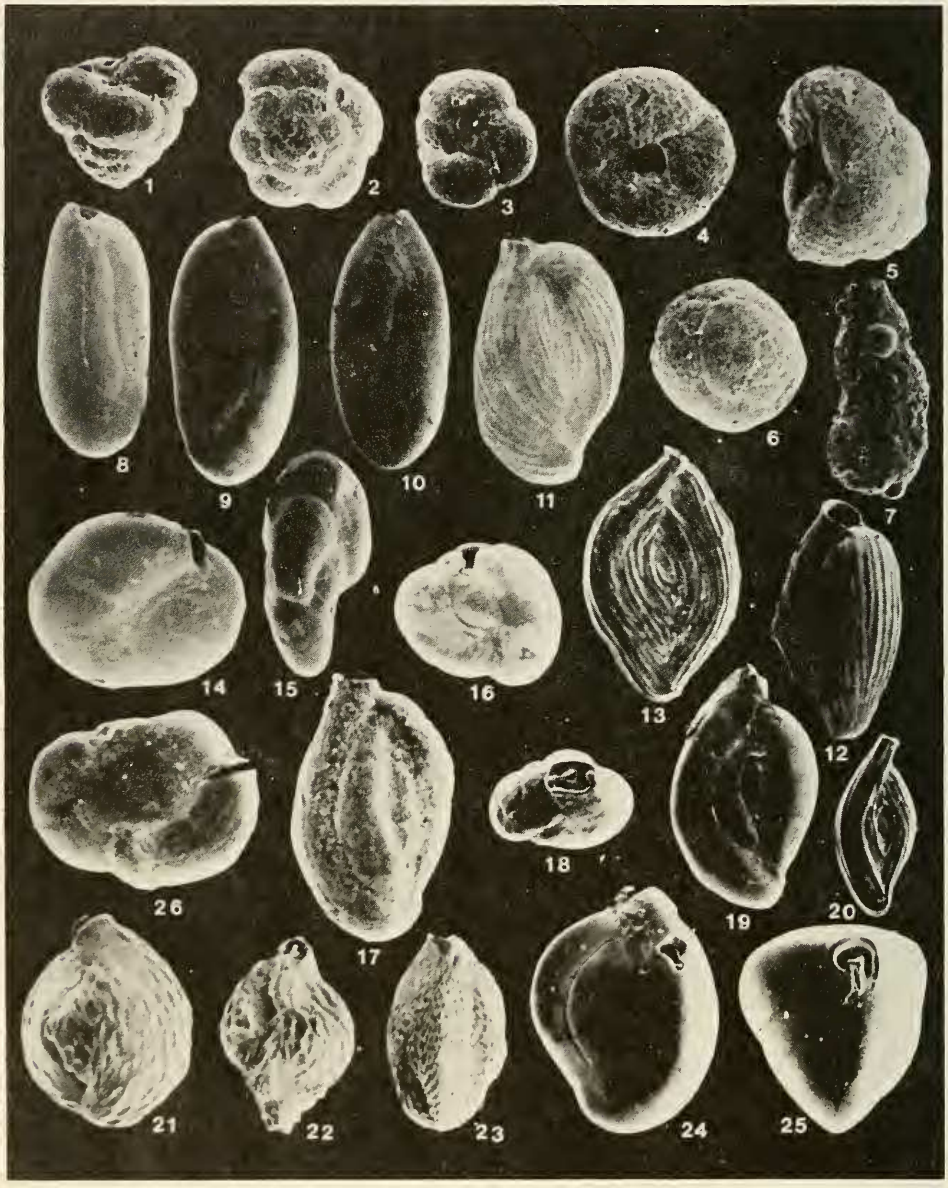
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Fig. 11. **1-3,** *Eggerella subconica* Sample Y41, Windang Island. x53 Umbilical, spiral and apertural views; **4-6,** *Tritaxis conica* Sample 282, tidal channel. x100 Apertural, lateral and spiral views; **7,** *Ammotium cassis* Sample Y30, Lake Illawarra. x56 Lateral view; **8-10,** *Triloculina oblonga* Sample Y33, Lake Illawarra. x70 Spiral and lateral views; **11-12,** *Quinqueloculina poeyana* Sample Y41, Windang Island. x57 Spiral and apertural views; **13, 20,** *Spiroloculina antillarum* Sample Y52, Windang Island. x31 Spiral views; **14-16,** *Miliolinella circularis* Sample Y42, Windang Island. x70 Spiral and apertural views; **17-18,** *Quinqueloculina tropicalis* Sample Y41, Windang Island. x70 Spiral and apertural views; **19,** *Spiroloculina communis* Sample Y52, Windang Island. x36 Spiral view; **21-22,** *Quinqueloculina* sp. nov. Sample Y52, Windang Island. x47 Spiral and apertural views; **23,** *Quinqueloculina pseudoreticulata* Sample Y19, tidal channel. x18 Apertural view; **24-25,** *Triloculina trigonula* Sample Y52, Windang Island. x61 Spiral and apertural views; **26,** *Miliolinella circularis* subsp. nov. Sample Y52, Windang Island. x43 Spiral view.

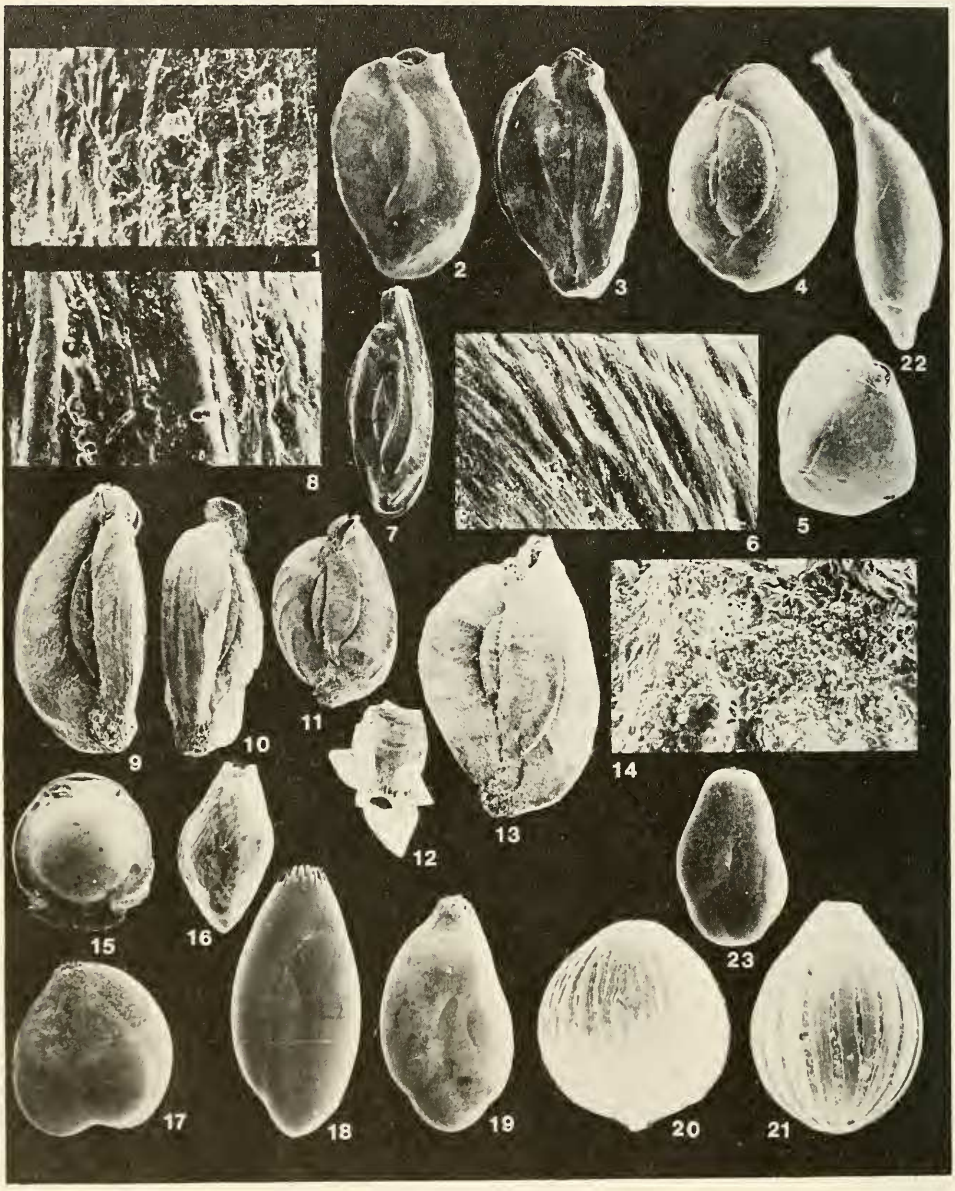
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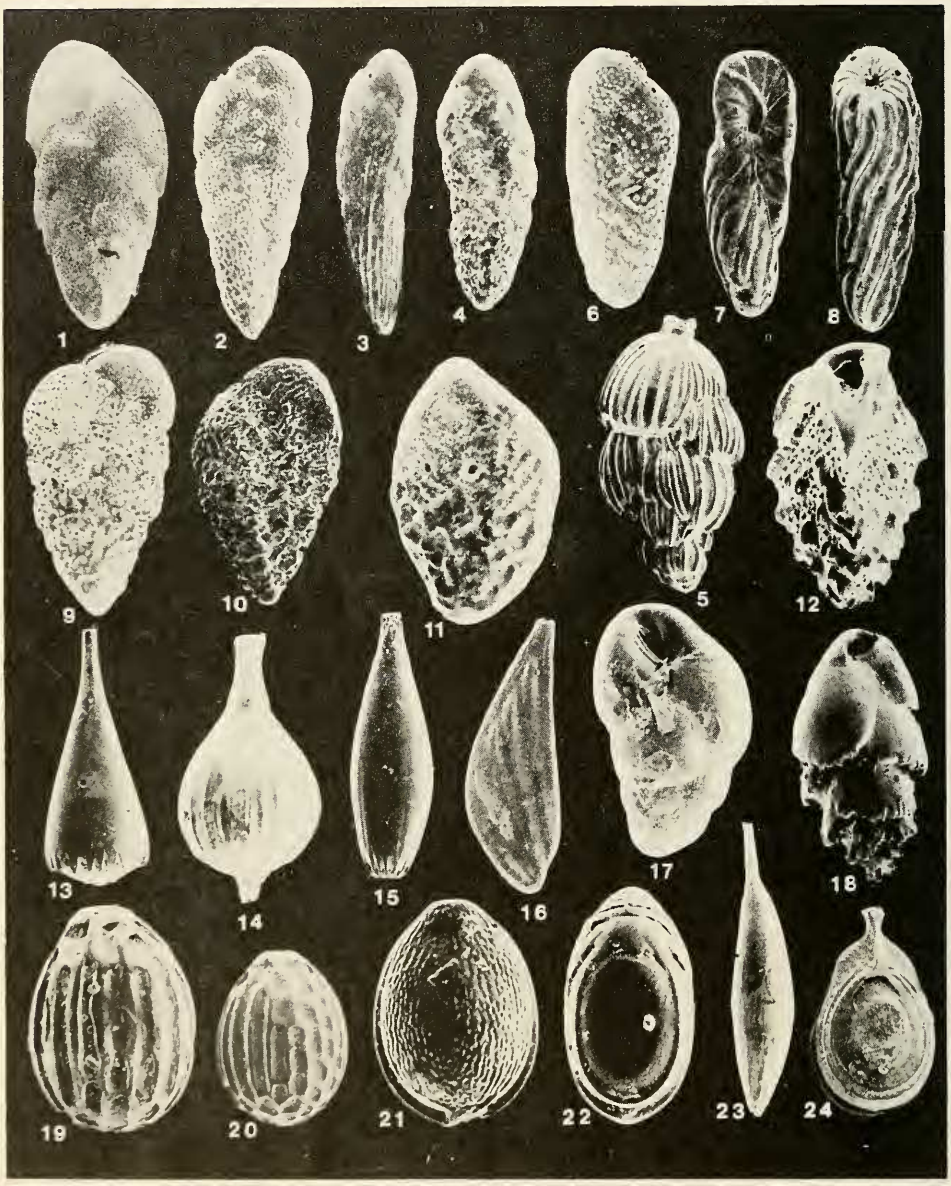
Fig. 12. **1-3,** *Quinqueloculina subpolygona* Sample Y52, Windang Island. Details of ornamentation (x460), spiral views (x31, x54); **4-6,** *Quinqueloculina seminula* Sample 282, tidal channel. Spiral and apertural views (x38), details of ornamentation (x460); **7-8,** *Quinqueloculina granulocostata* Sample Y41, Windang Island. Spiral view (x43), details of ornamentation (x460); **9-14,** *Miliolinella baragwanathi* Sample Y52, Windang Island. Lateral, spiral and apertural views (x72), details of ornamentation (x460); **15,** *Pyrgo subglobulus* Sample Y19, tidal channel. x40 Apertural view; **16,** *Quinqueloculina pseudoreticulata* Sample Y19, tidal channel. x40 Apertural view; **17,** *Sigmoidella elegantissima* Sample Y19, tidal channel. x32 Spiral view; **18,** *Guttulina pacifica* Sample Y19, tidal channel. x72 Spiral view; **19,** *Guttulina* sp. I Sample Y42, Windang Island. x48 Spiral view; **20,** *Oolina lineata* Sample Y19, tidal channel. x93 Lateral view; **21,** *Lagena acuticosta* Sample Y52, Windang Island. x91 Lateral view; **22,** *Lagena gracillima* Sample Y52, Windang Island. x79 Lateral view; **23,** *Guttulina* sp. II Sample Y19, tidal channel. x20 Lateral view.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APPENDIX

SPECIES IDENTIFIED FROM THE LAKE ILLAWARRA AREA

Characteristic features and surface ornamentation of foraminifers from the Lake Illawarra lagoonal, tidal channel and adjacent intertidal environments are listed and illustrated following the classification of Loeblich and Tappan (1964, 1974, 1984). The species are listed in alphabetical order within genera and families and the scanning electron microscope figures show the characteristic features used for their identification.

Family: Rzehakinidae Cushman, 1933
Genus: *Miliammina* Heron-Allen & Earland, 1930
Miliammina fusca (Brady, 1870) CPC 27318 (Fig. 10, nos 14-15)

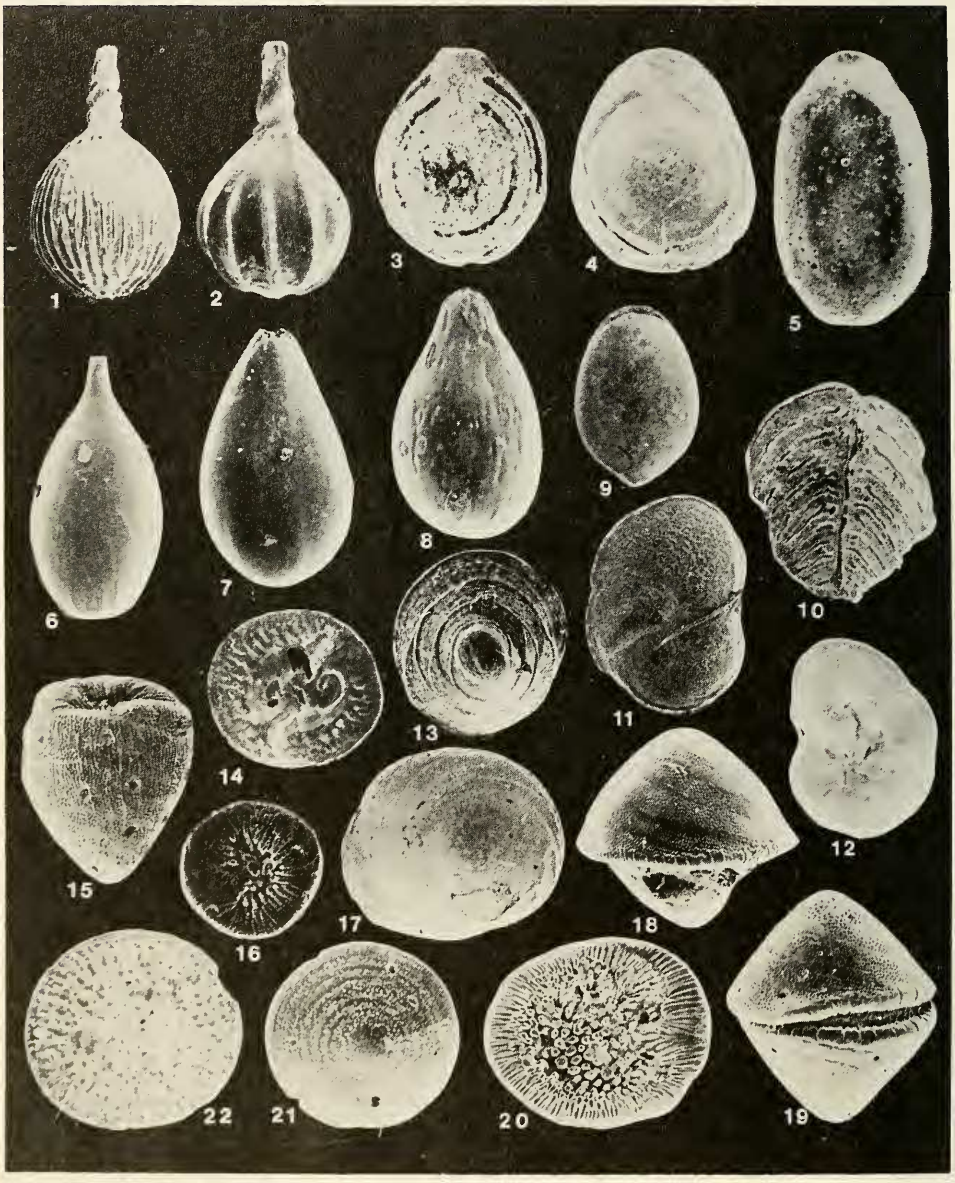
Family: Hormosinidae Haeckel, 1894
Genus: *Protoschista* Eimer & Fickert, 1899
Protoschista findens (Parker, 1870) CPC 27319 (Fig. 10, nos 10-11)
Genus: *Reophax* Montfort, 1808
Reophax sp. CPC 27320 (Fig. 10, nos 12-13)

Family: Lituolidae de Blainville, 1825
Genus: *Ammobaculites* Cushman, 1910
Ammobaculites agglutinans (d'Orbigny, 1846) CPC 27321 (Fig. 10, no. 5)
Ammobaculites foliaceus (Brady, 1881) CPC 27322 (Fig. 10, no. 4)
Ammobaculites sp. (Fig. 10, no. 6)
Genus: *Ammotium* Loeblich & Tappan, 1953
Amnotium cassis (Parker, 1870) CPC 27323 (Fig. 11, no. 7)
Genus: *Haplophragmoides* Cushman, 1910
Haplophragmoides canariensis (d'Orbigny, 1839) CPC 27324 (Fig. 10, nos 7-8)

Family: Trochamminidae Schwager, 1877
Genus: *Tritaxis* Schubert, 1921
Tritaxis conica (Parker & Jones, 1865) CPC 27325 (Fig. 11, nos 4-6)
Genus: *Trochammina* Parker & Jones, 1859
Trochammina inflata (Montagu, 1808) CPC 27326 (Fig. 10, nos 1-3)

Family: Textulariidae Ehrenberg, 1838
Genus: *Textularia* Defrance, *in* de Blainville, 1824
Textularia candeiana (d'Orbigny, 1839) CPC 27327 (Fig. 10, nos 23, 27)
Textularia porrecta (Brady, 1884) CPC 27328 (Fig. 10, no. 22)
Textularia sagittula (Defrance, 1824) CPC 27329 (Fig. 10, nos 24-25)
Textularia sp. I CPC 27330 (Fig. 10, no. 21)
Textularia sp. II (Fig. 10, no. 26)

Fig. 13. **1,** *Brizalina alata* Sample 282, tidal channel. x65 Lateral view; **2,** *Bolivina doniezi* Sample Y19, tidal channel. x70 Lateral view; **3,** *Brizalina striatula* Sample 282, tidal channel. x71 Lateral view; **4,** *Bolivina robusta* Sample Y19, tidal channel. x117 Lateral view; **5,** *Uvigerina bassensis* Sample 282, tidal channel. x67 Lateral view; **6,** *Bolivina perforatum* Sample Y19, tidal channel. x280 Lateral view; **7,** *Buliminoides gracilis* Sample Y19, tidal channel. x72 Lateral view; **8,** *Buliminoides williamsonianus* Sample Y19, tidal channel. x62 Lateral view; **9-10,** *Bolivina pseudoplicata* Sample Y19, tidal channel. x78, x85 Lateral view; **11,** *Bolivina* sp. Sample 282, tidal channel. x117 Lateral view; **12,** *Reussella spinulosa* Sample Y19, tidal channel. x70 Lateral view; **13,** *Lagena crenata* Sample 282, tidal channel. x86 Lateral view; **14,** *Lagena semilineata* Sample Y19, tidal channel. x122 Lateral view; **15,** *Lagena* cf. *implicata* Sample Y19, tidal channel. x68 Lateral view; **16,** *Planularia patens* Sample 282, tidal channel. x72 Lateral view; **17,** *Bulimina elongata subulata* Sample 282, tidal channel. x126 Lateral view; **18,** *Bulimina marginata* Sample Y19, tidal channel. x84 Lateral-apertural view; **19,20,** *Oolina striatopunctata gemma* Sample Y19, tidal channel. x193, x79 Lateral views; **21,** *Fissurina marginatoperforata* Sample Y19, tidal channel. x118 Lateral view; **22,** *Fissurina sulcata* Sample Y19, tidal channel. x123 Lateral view; **23,** *Lagena* cf. *gracillima* Sample Y19, tidal channel. x78 Lateral view; **24,** *Fissurina* sp. 1 Sample 282, tidal channel. x100 Lateral view.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Family: Ataxophragmiidae Schwager, 1877
Genus: *Eggerella* Cushman, 1933
Eggerella australis (Collins, 1958) CPC 27331 (Fig. 10, nos 17-20)
Eggerella subconica (Parr, 1950) CPC 27332 (Fig. 11, nos 1-3)
Genus: *Gaudryina* d'Orbigny, *in* de la Sagra, 1839
Gaudryina convexa (Karrer, 1865) CPC 27333 (Fig. 10, nos 9, 16)

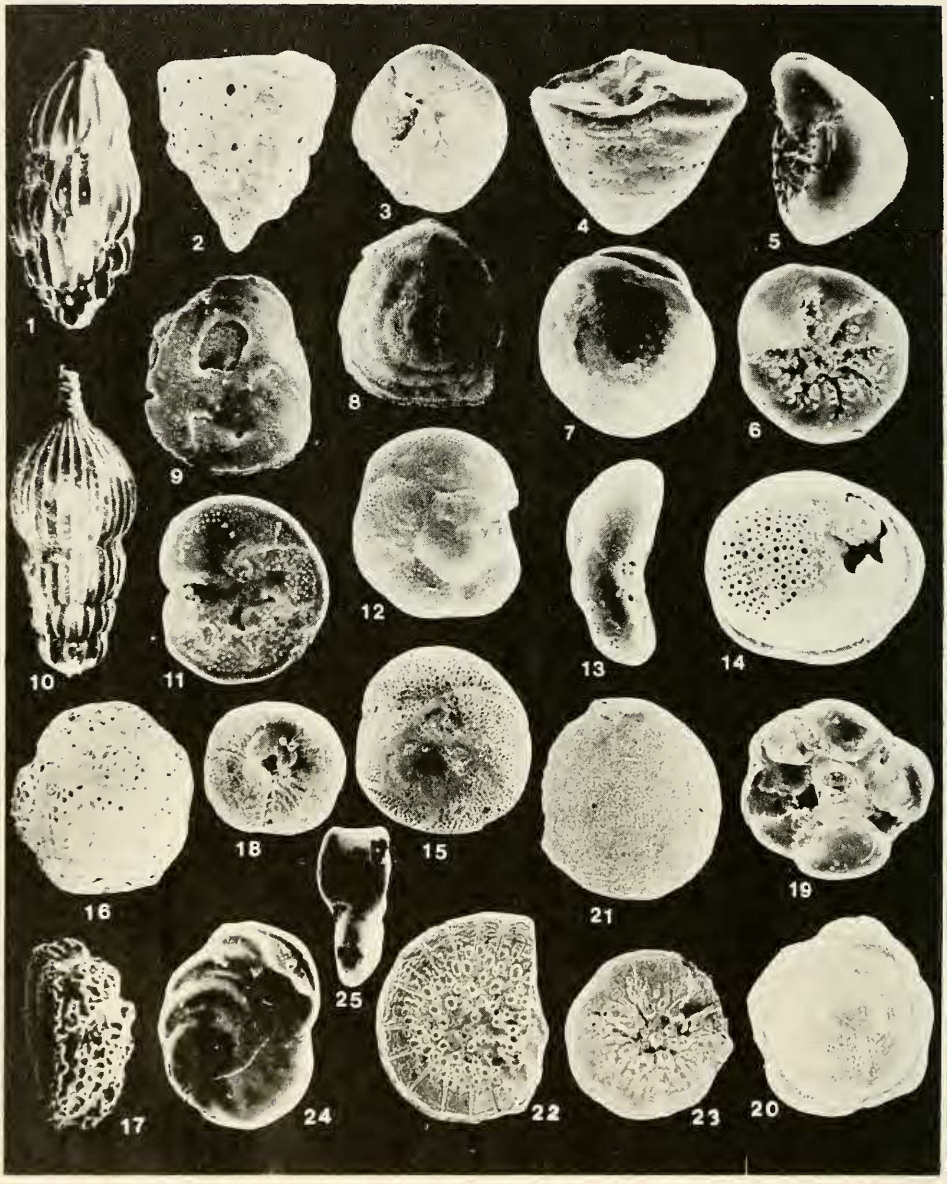
Family: Nubeculariidae Jones, 1875
Genus: *Spiroloculina* d'Orbigny, 1826
Spiroloculina antillarum (d'Orbigny, 1839) CPC 27334 & 27335 (Fig. 11, no. 13)
Spiroloculina communis (Cushman & Todd, 1944) (Fig. 11, no. 19)

Family: Miliolidae Ehrenberg, 1839
Genus: *Miliolinella* Wiesner, 1931
Miliolinella baragwanathi (Parr, 1945) CPC 27337 (Fig. 12, nos 9-14)
Miliolinella circularis (Bornemann, 1855) CPC 27338 (Fig. 11, nos 14-16)
Miliolinella circularis subsp. nov. CPC 27339 (Fig. 11, no. 26)
Miliolinella subrotunda (Montagu, 1803) (Fig. 19, nos 1-4)
Genus: *Pyrgo* Defrance, *in* de Blainville, 1824
Pyrgo subglobulus (Parr, 1950) CPC 27340 (Fig. 12, no. 15)
Genus: *Quinqueloculina* d'Orbigny, 1826
Quinqueloculina granulocostata (Germeraad, 1946) CPC 27341 (Fig. 12, nos 7-8)
Quinqueloculina poeyana (d'Orbigny, 1839) CPC 27342 (Fig. 11, nos 11-12)
Quinqueloculina pseudoreticulata (Parr, 1941) CPC 27343 (Fig. 11, no. 23, Fig. 12, no. 16)
Quinqueloculina seminula (Linné, 1767) CPC 27344 (Fig. 12, nos 4-6)
Quinqueloculina subpolygona (Parr, 1945) CPC 27345 (Fig. 12, nos 1-3)
Quinqueloculina tasmanica (Albani, 1978) CPC 27346 (Fig. 11, no. 20)
Quinqueloculina tropicalis (Cushman, 1924) CPC 27347 (Fig. 11, nos 17-18)
Quinqueloculina sp. nov. CPC 27348 (Fig. 11, nos 21-22)
Genus: *Triloculina* d'Orbigny, 1826
Triloculina oblonga (Montagu, 1803) CPC 27350 & 27351 (Fig. 11, no. 8-10)
Triloculina tricarinata (d'Orbigny, 1826)
Triloculina trigonula (Lamarck, 1804) CPC 27352 (Fig. 11, nos 24-25)

Family: Polymorphinidae d'Orbigny, 1839
Genus: *Guttulina* d'Orbigny, *in* de la Sagra, 1839
Guttulina pacifica (Cushman & Ozawa, 1928) CPC 27355 (Fig. 12, no. 18)
Guttulina regina (Brady, Jones & Parker, 1870) CPC 27356 (Fig. 19, no. 5)
Guttulina sp. I CPC 27357 (Fig. 12, no. 19)
Guttulina sp. II CPC 27358 (Fig. 12, no. 23)
Genus: *Sigmoidella* Cushman & Ozawa, 1928
Sigmoidella elegantissima (Parker & Jones, 1865) CPC 27359 (Fig. 12, no. 17)

Family: Nodosariidae Ehrenberg, 1838
Genus: *Amphicoryna* Schlumberger, *in* Milne-Edward, 1881
Amphicoryna scalaris (Batsch, 1791) CPC 27360 (Fig. 15, no. 10)

Fig. 14. **1,** *Lagena subacuticosta* Sample 282, tidal channel. x83 Lateral view; **2,** *Lagena sulcata* Sample 282, tidal channel. x117 Lateral view; **3,** *Fissurina lacunata* Sample Y19, tidal channel. x108 Lateral view; **4,** *Fissurina fasciata carinata* Sample Y52, Windang Island. x102 Lateral view; **5,** *Fissurina* cf. *subquadrata* Sample Y52, Windang Island. x118 Lateral view; **6,** *Lagena* cf. *semistriata* Sample Y19, tidal channel. x67 Lateral view; **7,** *Oolina* sp. I Sample Y19, tidal channel. x117 Lateral view; **8,** *Oolina* sp. II Sample 282, tidal channel. x101 Lateral view; **9,** *Fissurina* sp. II Sample Y19, tidal channel. x83 Lateral view; **10,** *Bolivinella folia* Sample Y19, tidal channel. x77 Lateral view; **11,** *Lamarckina* sp. Sample Y19, tidal channel. x71 Spiral view; **12,** *Lamarckina* sp. Sample Y42, Windang Island. x71 Umbilical view; **13-14,** *Patellina corrugata* Sample Y52, Windang Island. x87 Spiral and umbilical views; **15-16,** *Glabratella tabernacularis* Sample Y42, Windang Island. x91 Spiral and umbilical views; **17-20,** *Glabratella australensis* Sample Y52, Windang Island. x60, x91 Spiral, plastogamic and umbilical views; **21-22,** *Glabratella* sp. I. Sample Y52, Windang Island. x70 Umbilical and spiral views.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Genus: *Bolivinella* Cushman, 1927
Bolivinella folia (Parker & Jones, 1865) CPC 27361 (Fig. 14, no. 10)
Genus: *Fissurina* Reuss, 1850
Fissurina fasciata carinata (Sidebottom, 1906) CPC 27362 (Fig. 14, no. 4)
Fissurina lacunata (Burrows & Holland, 1895) CPC 27363 (Fig. 14, no. 3)
Fissurina marginatoperforata (Seguenza, 1913) CPC 27364 (Fig. 13, no. 21)
Fissurina sp. cf. *subquadrata* (Parr, 1945) CPC 27365 (Fig. 14, no. 5)
Fissurina sulcata (Collins, 1974) CPC 27366 (Fig. 13, no. 22)
Fissurina sp. I CPC 27367 (Fig. 13, no. 24)
Fissurina sp. II CPC 27368 (Fig. 14, no. 9)
Genus: *Lagena* Walker & Jacob, *in* Kanmacher, 1798
Lagena acuticosta (Reuss, 1861) CPC 27369 (Fig. 12, no. 21)
Lagena crenata (Parker & Jones, 1865) (Fig. 13, no. 13)
Lagena gracillima (Seguenza, 1862) CPC 27370 (Fig. 12, no. 22)
Lagena sp. cf. *gracillima* (Seguenza, 1862) CPC 27371 (Fig. 13, no. 23)
Lagena sp. cf. *implicata* (Cushman & McCulloch, 1950) CPC 27372 (Fig. 13, no. 15)
Lagena semilineata (Wright, 1866) CPC 27373 (Fig. 13, no. 14)
Lagena sp. cf. *semistriata* (Williamson, 1848) CPC 27374 (Fig. 14, no. 6)
Lagena subacuticosta (Parr, 1950) (Fig. 14, no. 1)
Lagena sulcata (Walker & Jacob, 1798) CPC 27375 (Fig. 14, no. 2)
Genus: *Planularia* Defrance, *in* de Blainville, 1824
Planularia patens (Brady, 1884) CPC 27376 (Fig. 13, no. 16)

Family: Glandulinidae Reuss, 1860
Genus: *Oolina* d'Orbigny, *in* de la Sagra, 1839
Oolina lineata (Williamson, 1848) CPC 27377 (Fig. 12, no. 20)
Oolina striatopunctata gemma (Cushman & McCulloch, 1950) CPC 27378 (Fig. 13, nos 19-20)
Oolina sp. I CPC 27379 (Fig. 14, no. 7)
Oolina sp. II CPC 27380 (Fig. 14, no. 8)

Family: Bolivinitidae Cushman, 1927
Genus: *Bolivina* d'Orbigny, *in* de la Sagra, 1839
Bolivina compacta (Sidebottom, 1905) CPC 27381
Bolivina doniezi (Cushman & Wickenden, 1928) (Fig. 13, no. 2)
Bolivina perforatum (Dinapoli, 1946) (Fig. 13, no. 6)
Bolivina pseudoplicata (Heron-Allen & Earland, 1930) CPC 27382 (Fig. 13, nos 9-10)
Bolivina robusta (Brady, 1881) CPC 27383 (Fig. 13, no. 4)
Bolivina sp. CPC 27384 (Fig. 13, no. 11)
Genus: *Brizalina* Costa, 1856
Brizalina alata (Seguenza, 1862) CPC 27385 (Fig. 13, no. 1)
Brizalina striatula (Cushman, 1922) CPC 27386 (Fig. 13, no. 3)

Family: Buliminidae Jones, 1875
Genus: *Bulimina* d'Orbigny, 1826
Bulimina elongata subulata (Cushman & Parker, 1937) (Fig. 13, no. 17)
Bulimina marginata (d'Orbigny, 1826) CPC 27388 (Fig. 13, no. 18)
Genus: *Reussella* Galloway, 1933
Reussella spinulosa (Reuss, 1850) CPC 27389 (Fig. 13, no. 12)

Fig. 15. **1,** *Uvigerina* cf. *peregrina* Sample Y19, tidal channel. x60 Lateral view; **2-3,** *Angulodiscorbis quadrangularis* Sample Y52, Windang Island. x93 Lateral and umbilical views; **4,** *Patellinella inconspicua* Sample Y42, Windang Island. x105 Umbilical and lateral views; **5-7,** *Buccella pustulosa* Sample Y52, Windang Island. x115 Apertural, umbilical and spiral views; **8-9,** *Rosalina anglica* Sample Y52, Windang Island. x48 Spiral and umbilical views; **10,** *Amphicoryna scalaris* Sample Y19, tidal channel. x60 Lateral view; **11-14,** *Rosalina bradyi* Sample Y52, Windang Island. x63 Umbilical, spiral, apertural and floating chamber views; **15,** *Rosalina australis* Sample Y52, Windang Island. x65 Spiral view; **16-18,** *Glabratella pulvinata* Sample Y52, Windang Island. x93 Spiral, lateral and umbilical views; **19-20,** *Cymbaloporetta bradyi* Sample Y52, Windang Island. x43 Umbilical and spiral views; **21-23,** *Glabratella* sp. II Sample Y19, tidal channel. x86 Spiral and umbilical views; **24-25,** *Planulinoides biconcavus* Sample 282, tidal channel. x65 Spiral and apertural views.

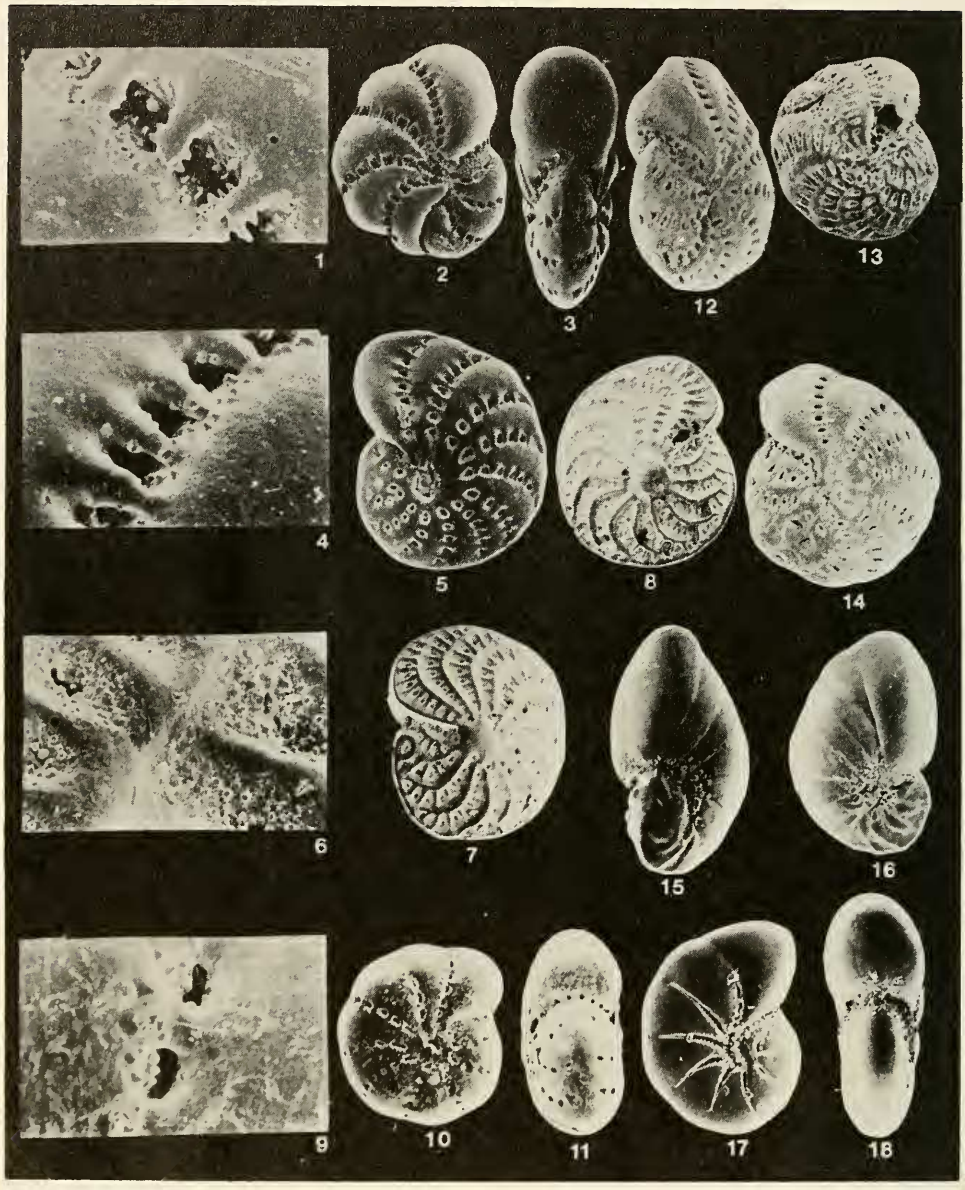


Fig. 16. **1-3,** *Elphidium depressulum* Sample Y52, Windang Island. Details of lateral process (x460), umbilical and apertural views (x80); **4-5,** *Elphidium advenum* Sample Y42, Windang Island. Details of lateral process (x460), and umbilical view (x87); **6-8,** *Elphidium macellum* Sample Y42, Windang Island. Details of lateral process (x460), and spiral view (x60); **9-11,** *Cribrononion sydneyensis* Sample 390, Lake Illawarra. Details of lateral process (x460), and spiral and apertural views (x50); **12-14,** *Elphidium argenteus* Sample Y52, Windang Island. x52 Lateral-apertural and umbilical views; **15-16,** *Nonionella auris* Sample Y19, tidal channel. x72 Lateral-apertural and umbilical views; **17-18,** *Nonion depressulus* Sample Y19, tidal channel. x87 Umbilical and apertural views.

Family: Turrilinidae Cushman, 1927
Genus: *Buliminoides* Cushman, 1911
Buliminoides gracilis (Collins, 1953) CPC 27391 (Fig. 13, no. 7)
Buliminoides williamsonianus (Brady, 1881) CPC 27392 (Fig. 13, no. 8)

Family: Uvigerinidae Haeckel, 1894
Genus: *Uvigerina* d'Orbigny, 1826
Uvigerina bassensis (Parr, 1950) CPC 27395 (Fig. 13, no. 5)
Uvigerina sp. cf. *peregrina* (Cushman, 1923) (Fig. 15, no. 1)

Family: Glabratellidae Loeblich & Tappan, 1963
Genus: *Angulodiscorbis* Uchio, 1953
Angulodiscorbis quadrangularis (Uchio, 1953) CPC 27396 (Fig. 15, nos 2-3)
Genus: *Glabratella* Dorreen, 1948
Glabratella australensis (Heron-Allen & Earland, 1932) CPC 27397 (Fig. 14, nos 17-20)
Glabratella sp. cf. *parri* (Collins, 1974)
Glabratella patelliformis (Brady, 1884) CPC 27398
Glabratella pulvinata (Brady, 1884) CPC 27399 (Fig. 15, nos 16-18)
Glabratella tabernacularis (Brady, 1884) CPC 27400 (Fig. 14, nos 15-16)
Glabratella sp. I CPC 27401 (Fig. 14, nos 21-22)
Glabratella sp. II CPC 27402 (Fig. 15, nos 21-23)

Family: Discorbidae Ehrenberg, 1838
Genus: *Baggina* Cushman, 1926
Baggina phillippinensis (Cushman, 1921) CPC 27403 (Fig. 17, nos 18-19)
Genus: *Buccella* Andersen, 1952
Buccella pustulosa (Albani, 1982) CPC 27404 (Fig. 15, nos 5-7)
Genus: *Discorbinella* Bandy, 1949
Discorbinella bertheloti (d'Orbigny, 1839) CPC 27405 (Fig. 18, nos 13-14)
Discorbinella planoconcava (Chapman, Parr & Collins, 1932) CPC 27406 (Fig. 18, no. 25)
Genus: *Lamellodiscorbis* Bermudez, 1952
Lamellodiscorbis dimidiatus (Jones & Parker, 1862) CPC 27407 (Fig. 17,nos 9-11)
Genus: *Patellinella* Cushman, 1928
Patellinella inconspicua (Brady, 1884) CPC 27408 (Fig. 15, no. 4)
Genus: *Planulinoides* Parr, 1941
Planulinoides biconcavus (Jones & Parker, 1862) CPC 27409 (Fig. 15, nos 24-25)

Family: Rosalinidae Reiss, 1963
Genus: *Rosalina* d'Orbigny, 1826
Rosalina anglica (Cushman, 1931) CPC 27410 (Fig. 15, nos 8-9)
Rosalina australis (Parr, 1932) CPC 27411 (Fig. 15, no. 15)
Rosalina bradyi (Cushman, 1951) CPC 27412 (Fig. 15, nos 11-14)

Family: Robertinidae Reuss, 1850
Genus: *Lamarckina* Berthelin, 1881
Lamarckina sp. CPC 27413 (Fig. 14, nos 11-12)

Family: Cymbaloporidae Cushman, 1927
Genus: *Cymbaloporetta* Cushamn, 1928
Cymbaloporetta bradyi (Cushman, 1915) CPC 27414 & 27415 (Fig. 15, nos 19-20)

Family: Planorbulinidae Schwager, 1877
Genus: *Acervulina* Schultz, 1854
Acervulina inhaerens (Schultze, 1854) CPC 27416 & 27417 (Fig. 17, nos 14-15)
Genus: *Planorbulina* d'Orbigny, 1826
Planorbulina mediterranensis (d'Orbigny, 1826) CPC 27418 (Fig. 17, no. 12)

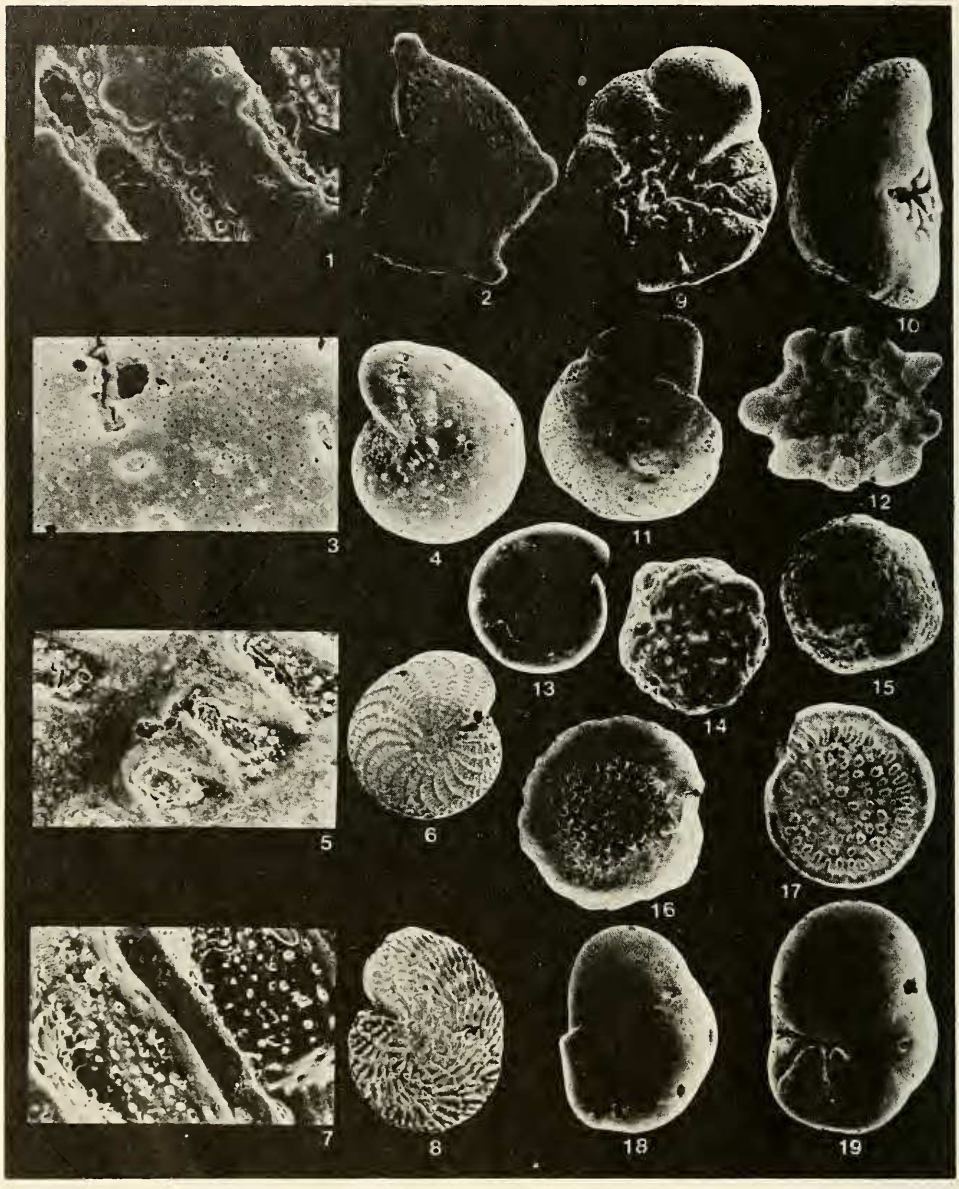


Fig. 17. **1-2,** *Parrellina imperatrix* Sample Y42, Windang Island. Details of lateral process (x460), and spiral view (x20); **3-4,** *Elphidium* sp. Sample Y19, tidal channel. Details of lateral process (x460), and spiral view (x91); **5-6,** *Elphidium crispum* Sample 282, tidal channel. Details of lateral process (x460), and spiral view (x31); **7-8,** *Elphidium jenseni* Sample 282, tidal channel. Details of lateral process (x460), and spiral view (x20); **9-11,** *Lamellodiscorbis dimidiatus* Sample Y52, Windang Island. x26 Umbilical, lateral-apertural and spiral views; **12,** *Planorbulina mediterranensis* Sample Y18, tidal channel. x27 Spiral view; **13,** *Spirillina vivipara* Sample 282, tidal channel. x86 Spiral view; **14-15,** *Acervulina inhaerens* Sample Y52, Windang Island. x63 Umbilical and spiral views; **16,** *Spirillina tuberculata* Sample Y19, tidal channel. x55 Umbilical view; **17,** *Spirillina* sp. Sample Y19, tidal channel. x95 Umbilical view; **18-19,** *Baggina phillippinensis* Sample Y52, Windang Island. x52 Spiral and umbilical views.

Family: Elphidiidae Galloway, 1933
Genus: *Cribrononion* Thalmann, 1947
Cribrononion sydneyensis (Albani, 1978) CPC 27424 (Fig. 16, nos 9-11)
Genus: *Elphidium* Montfort, 1808
Elphidium advenum (Cushman, 1922) CPC 27425 (Fig. 16, nos 4-5)
Elphidium argenteus (Parr, 1945) CPC 27426 (Fig. 16, nos 12-14)
Elphidium crispum (Linne, 1758) CPC 27427 (Fig. 17, nos 5-6)
Elphidium depressulum (Cushman, 1933) (Fig. 16, nos 1-3)
Elphidium jenseni (Cushman, 1924) CPC 27428 (Fig. 17, nos 7-8)
Elphidium macellum (Fichtel & Moll, 1798) CPC 27429 (Fig. 16, nos 6-8)
Elphidium sp. CPC 27430 (Fig. 17, nos 3-4)
Genus: *Parrellina* Phalmann, 1951
Parrellina imperatrix (Brady, 1881) CPC 27431 (Fig. 17, nos 1-2)

Family: Nonionidae Schultze, 1854
Genus: *Nonion* Montfort, 1808
Nonion depressulus (Walker & Jacob, 1798) (Fig. 16, nos 17-18)
Genus: *Nonionella* Cushman, 1926
Nonionella auris (d'Orbigny, 1839) CPC 27434 (Fig. 16, nos 15-16)

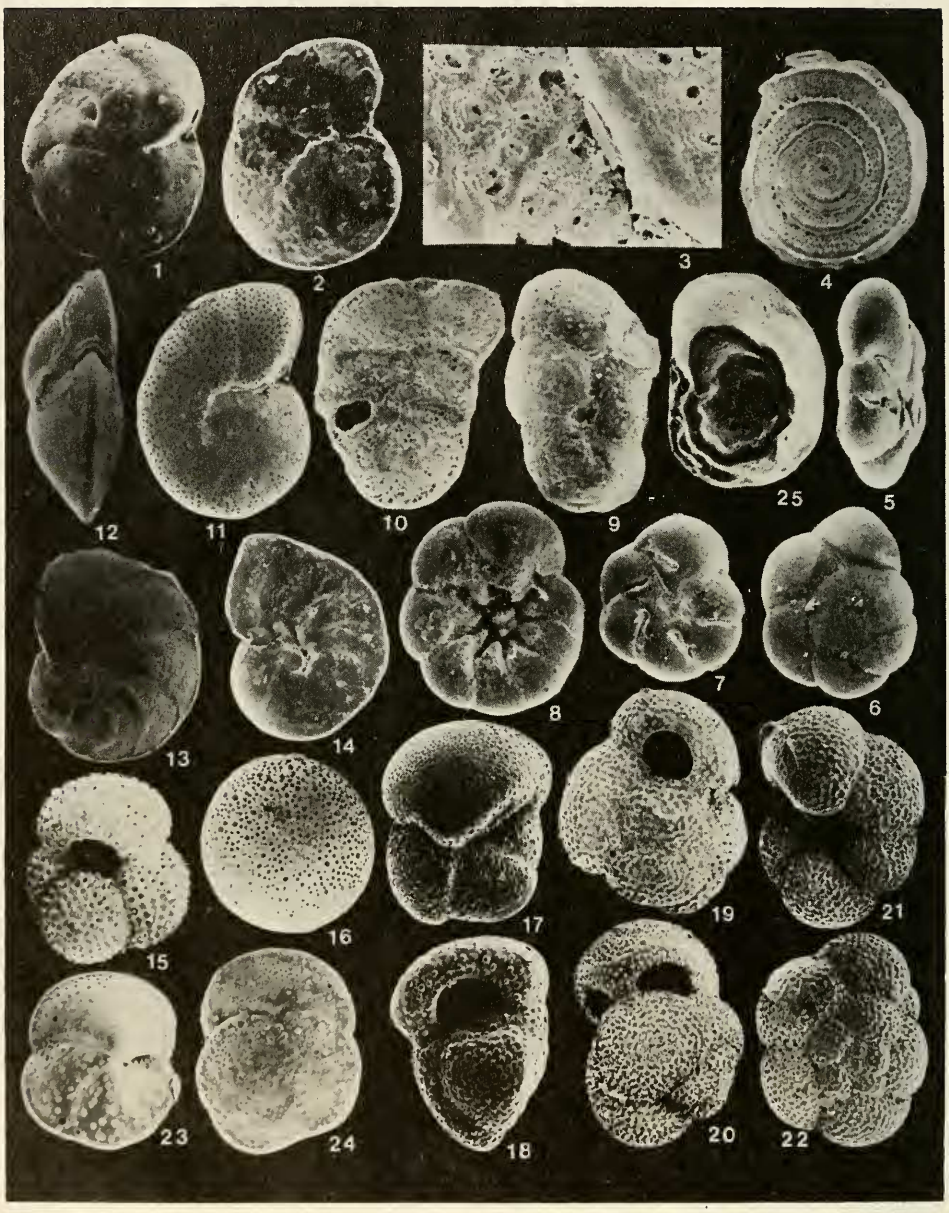
Family: Rotaliidae Ehrenberg, 1839
Genus: *Ammonia* Brünnich, 1772
Ammonia beccarii (Linné, 1767) CPC 27432 (Fig. 18, no. 8)
Genus: *Rotalia* Lamarck, 1804
Rotalia perlucida (Heron-Allen & Earland, 1913) CPC 27433 (Fig. 18, nos 5-7)

Family: Cibicididae Cushman, 1927
Genus: *Cibicides* Montfort, 1808
Cibicides cygnorum (Carter, 1964) CPC 27419 (Fig. 18, nos 1-2, 12)
Cibicides refulgens (Montfort, 1808) CPC 27420
Genus: *Dyocibicides* Cushman & Valentine, 1930
Dyocibicides biserialis (Cushman & Valentine, 1930) CPC 27421 (Fig. 18, nos 9-10)

Family: Anomalinidae Cushman, 1927
Genus: *Anomalina* d'Orbigny, 1826
Anomalina nonionoides (Parr, 1932) CPC 27435 (Fig. 18, no. 11)

Family: Spirillinidae Reuss, 1862
Genus: *Patellina* Williamson, 1858
Patellina corrugata (Williamson, 1858) CPC 27436 (Fig. 14, nos 13-14)
Genus: *Spirillina* Ehrenberg, 1843
Spirillina denticulata (Brady, 1884) CPC 27437 (Fig. 18, nos 3-4)
Spirillina inaequalis (Brady, 1879) CPC 27438
Spirillina tuberculata (Brady, 1884) CPC 27439 (Fig. 17, no. 16)
Spirillina vivipara (Ehrenberg, 1843) CPC 27440 (Fig. 17, no. 13)
Spirillina sp. CPC 27441 (Fig. 17, no. 17)

Family: Globigerinidae d'Orbigny, 1826
Genus: *Globigerina* d'Orbigny, 1826
Globigerina bulloides (d'Orbigny, 1826) CPC 27442 (Fig. 18, no. 15)
Globigerina sp.
Genus: *Globigerinoides* Cushman, 1927
Globigerinoides ruber (d'Orbigny, 1839) CPC 27443 (Fig. 18, nos 19-20)
Genus: *Globoquadrina* Finlay, 1947
Globoquadrina dutertrei (d'Orbigny, 1839) CPC 27444 (Fig. 18, nos 21-22)
Genus: *Orbulina* d'Orbigny, *in* de la Sagra, 1839
Orbulina universa (d'Orbigny, 1839) CPC 27445 (Fig. 18, no. 16)
Genus: *Pulleniatina* Cushman, 1927
Pulleniatina obliquelocula (Parker & Jones, 1865)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Family: Globorotaliidae Cushman, 1927
Genus: *Globorotalia* Cushman, 1927
Globorotalia hirsuta (d'Orbigny, 1839) CPC 27446 (Fig. 18, nos 23-24)
Subgenus: *Turborotalia* Cushman & Bermudez, 1949
Globorotalia (Turborotalia) inflata (d'Orbigny, 1839) CPC 27447 (Fig. 18, nos 17-18)

Fig. 18. **1-2, 12,** *Cibicides cygnorum* Sample 282, tidal channel. x78 Umbilical, spiral and apertural views; **3-4,** *Spirillina denticulata* Sample Y19, tidal channel. Details of ornamentation (x460), and spiral view (x74); **5-7,** *Rotalia perlucida* Sample Y52, Windang Island. x70 Apertural, spiral and umbilical views; **8,** *Ammonia beccarii* Sample Y10, Lake Illawarra. x43 Umbilical view; **9-10,** *Dyocibicides biserialis* Sample Y42, Windang Island. x43 Umbilical and spiral views; **11,** *Anomalina nonionoides* Sample Y19, tidal channel. x50 Spiral view; **13-14,** *Discorbinella bertheloti* Sample Y19, tidal channel. x87 Spiral and umbilical views; **15,** *Globigerina bulloides* Sample Y19, tidal channel. x71 Umbilical view; **16,** *Orbulina universa* Sample Y19, tidal channel. x64; **17-18,** *Globorotalia (Turborotalia) inflata* Sample 282, tidal channel. x71 Umbilical and apertural views; **19-20,** *Globigerinoides ruber* Sample Y19, tidal channel. x72 Spiral, lateral-apertural views; **21-22,** *Globoquadrina dutertrei* Sample Y19, tidal channel. x70 Umbilical and spiral views; **23-24,** *Globorotalia hirsuta* Sample Y19, tidal channel. x70 Umbilical and spiral views; **25,** *Discorbinella planoconcava* Sample Y42, Windang Island. x90 Umbilical view.

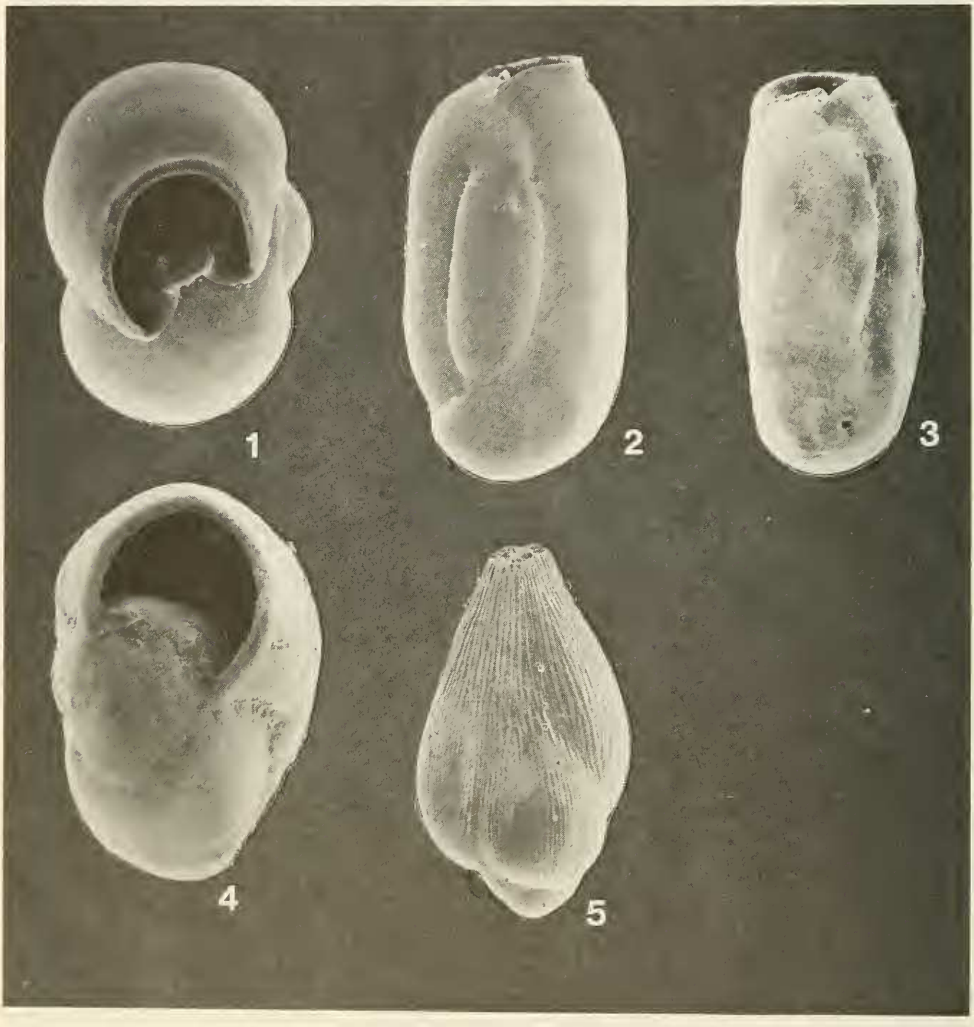

Fig. 19. **1-4,** *Miliolinella subrotunda* Sample Y28, Lake Illawarra. 1, 4 apertural views (x200); 2 spiral view (x170); 3 lateral view (x160); **5**, *Guttulina regina* Sample Y42, Windang Island. x60 Lateral view.